Fire Performance of Gable Frame Structures

By

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Abstract

Fire protection engineering and structural engineering are two relevant but separated fields of study. Many experiments conducted by fire protection engineers are under certain ideal boundary conditions, which may not be applicable for real compartment fires. There is sophisticated software that is able to predict the dynamics of fire indoors, but it requires a lot of computation time and power to run such simulation. The results attained with traditional analytical methods can be extremely conservative, which poses the problem whether or not such approach is necessary; is there a better way to concur on such issues?

In recent years, structural engineers have tried to identify ways to optimize structures to make them more efficient for carrying loads such as wind and earthquake. Few studies have been done on structure optimization for fire. As an unpredictable event, fire can occur under many circumstances, such as after earthquakes and blast events. The main cause of structural failure of the World Trade Center towers after the impact was the fire exposure.

This thesis outlines a study of three-hinge gable frame's fire performance, and identifies the fire rating differences between testing fire and real compartment fire. Warehouses are commonly built for material storage, which can be inflammable and produce toxins. However, many of them were not designed to withstand unpredictable events such as fire. Therefore, it becomes essential to determine whether or not they have achieved a certain level of fire safety. Steel and timber are two of the most frequently used materials in construction, but when they are exposed to fire, steel losses its strength, and timber burns and losses its cross section area.

Three identical gable frames were designed with timber, unprotected steel, and protected steel. All three structures were analyzed with various fire conditions, lab testing fires and compartment fires. The compartment fires were simulated with software called Fire Dynamic Simulator, and the non-linear behavior of timber under elevated temperature was determined using Finite Element Method with ANSYS.

Thesis Supervisor: Jerome J. Connor
Title: Professor of Civil and Environmental Engineering

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First, I would like to thank my parents and other family members for their constant support and unconditional love, without you, I would not be sitting here and finishing this thesis. It must be very hard for my parents to send their only child thousands miles away from home, but it is you who made it possible for me to explore a much bigger world, to achieve such success, and to become a better man.

I would also like to thank Professor Connor for all his advices in this past year. He is always there to give me sincere help, regardless if it is relevant to academic works. I really appreciate his help.

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1 Introduction

Warehouses are one of the most commonly seen building structures, and serve as storage space for many businesses, such as manufacturing, importing or exporting, transportation, etc. It is normally a large, plain one-story structure. For a low-budget structure like a warehouse, it is typically built up with a simple structure system. Long span portal frames and gable frames are commonly used in such constructions.

There are numerous warehouses used to store inflammable or toxic materials, and they could be located in factories, airports, seaports, or even in cities and residential neighborhoods. Structural failures of such warehouses will result in catastrophic consequences, such as losing lives, releasing hazardous materials, and damaging properties. However, such low budget structures are typically not designed to survive extreme events like fires. Many fire incidents are reported every year, and the damage done is devastating. Figure 1 shows the aftermath of warehouse fires, and in the second picture, the structural collapse was due to elevated temperature.

Figure 1: a) Aftermath of a warehouse fire[1]. b) Aerial view of the fatal fire in 2007 at the warehouse in Atherstone on Stour, Warwickshire[2]

Fire is an unpredictable event, but there are many methods to prevent it from happening or to minimize the damages. Most of those approaches require additional investment during both the design and construction processes. All the building design codes now have stated the minimum design requirements for structural performance during fire to allow the occupants to safely leave the structure. Therefore, new constructed warehouses are required to pass those fire ratings.

[1] (Warehouse & Logistics News)
[2] (Parsons)

However, there are many different construction strategies that can be applied, and it is necessary to evaluate them.

Timber and steel are the two most commonly used materials in warehouse construction, but their behavior and performance during fire are completely different. Therefore, three case studies were established: timber, unprotected steel and protected steel structures. In addition, multiple fire scenarios were introduced. This way, by comparing the results, one can identify which would be the ideal material to use for warehouse construction, and visualize the amount of structural damage done and necessary restoration required after the fire.

1.1 Warehouse

The warehouse used in this study had a width of 40m and a length of 80m, and its eave height h_e was 10m, height at the tip of the pitched roof was 15m (See Figure 2). It was designed to be supported by a series of gable frames, which are a commonly seen structural system used in warehouse construction. The particular type of gable frame used for this study was a three-hinge frame. In addition to the pin-supports on both columns, there was a hinge connection at the apex of the pitched roof. Due to the long span roofing members in each frame, the spacing between each of them was set to be 5m.

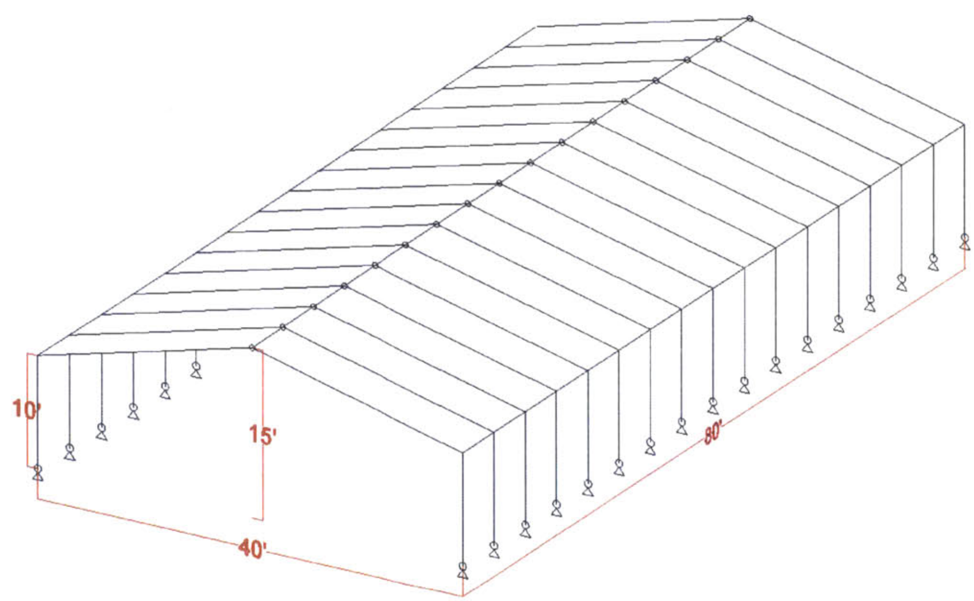

Figure 2: Warehouse structural layout

1.1.1 Timber

Wood is frequently used on building structures because of its high strength and low self-weight compared to most other construction material. However, timber is an inflammable organic material, and generally thought of as one of the worst materials in terms of withstanding fire. The truth is heavy timber construction has become recognized as having very good fire-resistance[3]. In Figure 3, one can clearly see that, under a compartment fire, the timber member performs much better than the steel members. Instead of collapsing the structure completely, it is still supporting the heavily deformed steel I-Beams.

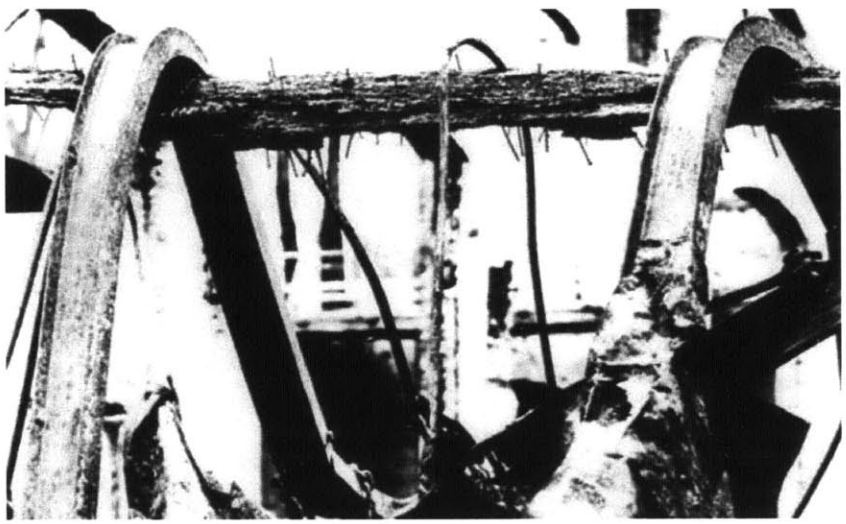

Figure 3: Steel beams have melted and collapsed over charred timber beam, which, despite heavy damage, remains in place[4]

Glulam, also known as 'glue laminated timber', is a type of manufactured timber structural material. It can be manufactured into any desired shape and size, and it behaves the same way as an identical size solid sawn-timber would under elevated temperature, which is proven by many previous fire tests. Thus, it will be used in this study to design the warehouse members instead of saw lumber due to their sizes and irregular geometric shape.

The reason that wood performs great in fire is that when exposed to fire, the surface of the wood will burn rapidly and form a layer of char, which behaves as great insulation for the wood below[5].

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[3] (Buchanan)
[4] (American Institute of Timber Construction)
[5] (Buchanan)

With the temperature of the wood below the char layer being heated over 100 °C, the moisture evaporates and travels both out the burning surface and into the wood, which increases the moisture content in the wood below[6]. In order to further improve wood's durability in fire, some fire-resistant agents are added into wood members during manufacturing.

1.1.2 Steel

Steel is the most commonly used structural material for warehouse construction. As with all other metals, steel has a high thermal conductivity value. Thus, heat is able to travel across the cross-section of a steel member instantly. However, the rate of changing steel temperature fully depends on the severity of the fire, the section factor A_p/V of the steel member that is exposed to the fire (see Table 1), and the amount of fire protection that is applied. This means, when two identical steel members are subjected to the same heat source, the one with more surface area contacts with fire will have a higher rate of temperature increase.

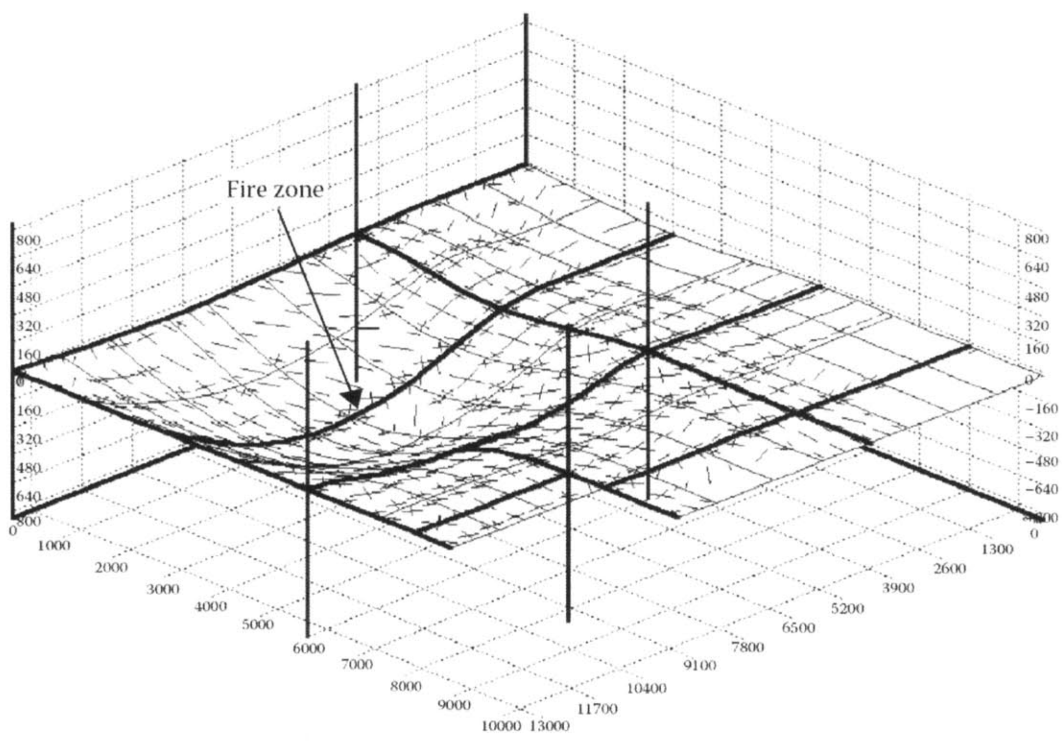


Figure 4: Deflected shape of the steel and composite frames under fire[7]

[6] (Buchanan)
[7] (Wang, Burgess and Wald)

Unprotected steel structure tends to perform poorly in fires compared with reinforced concrete or heavy timber structures, because the steel members are usually much thinner[8]. When it is heated, many of its physical properties are reduced with increasing temperature. As shown in Figure 4, beams in the fire zone start sagging. The one located in the middle of the zone deflects the most, and will eventually lose all its bending strength and collapse the entire structural bay. On the other hand, when a column is heated, it will lose its axial capacity. When the load is concentric, the column will squash, but when eccentric load or bending moment is applied, the column will buckle (See Figure 5).

Figure 5: Column squashing in Plane frame test[9]

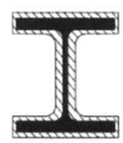
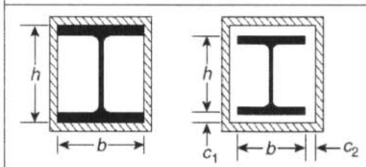
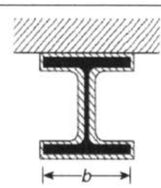
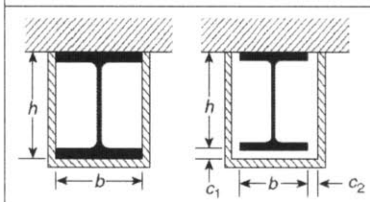
1.1.3 Protected Steel

When engineers realized that heat is the biggest weakness for steel structure, many different methods were introduced to enhance its performance during a fire. Decreasing the rate of temperature rise in the steel and adding enough redundancy into the structure so it will not fail so easily are two main methods. Comparison of these two methods shows that applying fireproof materials is clearly the more economical and reliable approach of the two. Coating the structure with fireproof material provides a barrier between the heated air and main structural member to

[8] (Buchanan)
[9] (Lamont)

minimize the amount of heat that will be transferred to and absorbed by the steel. An alternative way is filling hollow steel members with low thermal conductivity material, such as concrete and water. Those insolation materials are able to absorb most heat from steel instantly when it is heated.

Table 1: Fire protection method and section factor A_p/V, in steel structure[10]

Sketch	Description	Section factor A_p/V
	Contour encasement of uniform thickness	steel perimeter / steel cross-section area
	Hollow encasement of uniform thickness[1]	$2(b + h)$ / steel cross-section area
	Contour encasement of uniform thickness, exposed to fire on three sides	steel perimeter − b / steel cross-section area
	Hollow encasement of uniform thickness, exposed to fire on three sides[1]	$2h + b$ / steel cross-section area

[1] The clearance dimensions c_1 and c_2 should not normally exceed $h/4$

Table 2: Thickness of proprietary spray-on protection required to provide fire resistance to a steel beam or column[11]

Section Size		Fire Resistance			
F/V (m^-1)	V/F (mm)	1 hour	2 hours	3 hours	4 hours
70	14.3	10	22	36	50
110	9.1	10	28	47	65
150	6.7	12	33	54	75
190	5.3	13	37	60	83
230	4.3	14	39	64	89
270	3.7	15	41	68	94

[10] (Franssen, Kodur and Zaharia)
[11] (ASFPCM)

As shown in Table 1, coating a steel member can either be done by applying spray-on fireproof substance or encasing the steel members with boards, which is commonly used on exposed columns. For the spray-on fireproofing, in order to achieve the desired purpose, the steel members have to be fully coated to prevent any direct contact between the heated air and itself. Depending on the importance factor and geometric properties of the member, the thickness of the fireproofing can vary from 10mm to 94mm to achieve different fire ratings (See Table 2). In Table 3, the properties of different insulation materials are listed. The sprays are the most frequently used coating materials, and the boards are only used by clients who have specific requirements for architectural purposes.

Table 3: Thermal properties of insulation materials

Material	Density ρ_i (kg/m^3)	Thermal Conductivity k_i (W/mK)	Specific Heat c_i (J/kgK)	Equilibrium Moisture Content %
Sprays:				
Sprayed Mineral Fibre	300	0.12	1200	1
Perlite or Vermiculite Plaster	350	0.12	1200	15
High-Density Perlite or Vermiculite Plaster	550	0.12	1200	15
Boards:				
Fibre-Silicate or Fibre-Calcium Silicate	600	0.15	1200	3
Gypsum Plaster	800	0.2	1700	20
Compressed Fibre Boards:				
Mineral Wool, Fibre Silicate	150	0.2	1200	2

Concrete has great performance under elevated temperature, and acts as a heat sink for other structural members that have direct contact with it. This is because of its non-combustible and low thermal conductivity characteristic. The cement paste in concrete undergoes an endothermic reaction when being heated, which assists in reducing the temperature rising rate during elevated temperature while a large amount heat is being absorbed[12]. It is frequently used as an infill material for axial loaded members, whose compression capacity and thermal rating are both improved. Instead of concrete, one can also fill the hollow tube structure with water to achieve the same fireproofing purpose, such as the building located on 80 Cannon Street, in London (Figure 6). The exoskeleton of this building is designed by Arup Associates with this method to achieve fire protection purpose.

[12] (Buchanan)

Figure 6: 80 Cannon Street, London, UK[13]

Between these two fireproofing methods, coating major steel members with sprays is more frequently seen, because it is lighter in weight and more economical. For a low cost warehouse, it is more reasonable to use spray-on protection.

1.2 Design Fires

In order to define the thermal performance of the studying gable frames, a list of time-temperature curves is defined. Two methods are used to generate the proper exposure temperature: Analytical Methods and Numerical Methods. Elevating rate of fire temperature varies with many factors, such as ventilation and fuel load. An idealized laboratory fire behaves differently from an uncontrolled compartment fire for this reason. In analytical analysis, three curves are developed. They are the temperatures recorded from testing fires with controlled boundary conditions. However, the boundary conditions of a compartment fire might not be clearly defined, and they vary over time with respect to the dynamics of fire. Therefore, three

[13] http://www.80cannonstreet.co.uk/image/gallery1.jpg

numerical models were adapted to simulate the possible temperature variation under real fire with uncontrolled boundary conditions.

1.2.1 Analytical Method – Idealized Temperature Course of Fire

Many design codes, such as *American Society for Testing and Materials (ASTM), Eurocode, and International Organization of Standardization (ISO)*, have provided standard time temperature curves that are used to rate the individual performance of building assemblies. However, as mentioned in *ASTM E119-12a*[14], they do not incorporate all factors required for fire hazard or fire risk assessment of any products under actual fire conditions. It is conducted to identify the fire rating of different materials during the study. The results from using a standard fire are generally very conservative due to its nature. Figure 7 shows the time temperature curve of *ASTM E119* curve, and temperature data can be found in Appendix A.

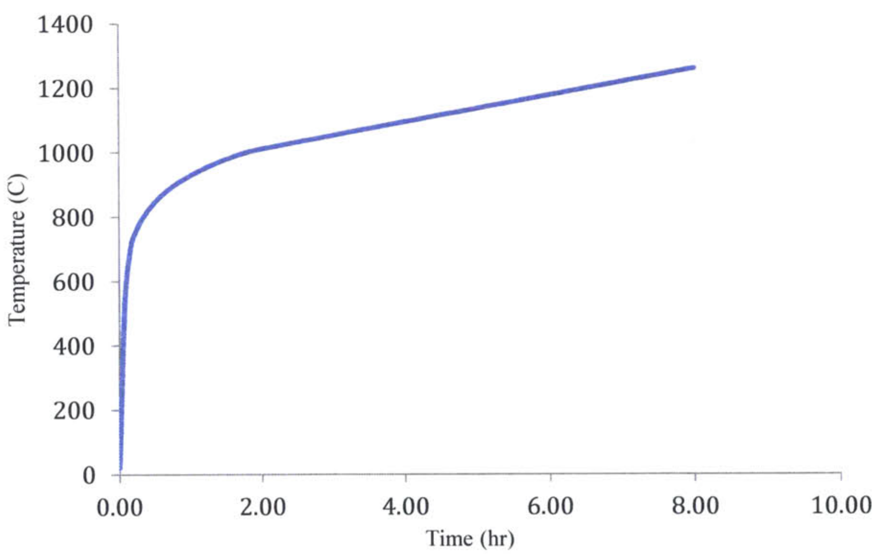


Figure 7: ASTM E-119 Curve

Long duration-low intensity fire and short duration-high intensity fire are designed laboratory fires to simulate the behavior of 'natural' fires for analytical purposes. The gas temperatures of

[14] (ASTM Standards E119, 2012a)

these two fire curves can be calculated using the equation provided in Chapter 4-8[15] from the *SFPE Handbook of Fire Protection Engineering*, which is also listed below.

$$T = 250(10F)^{0.1/F^{0.3}}e^{-F^{2}t}[3(1-e^{-0.6t})-(1-e^{-3t})+4(1-e^{-12t})]+C\left(\frac{600}{F}\right)^{0.5}$$

$$T = the\ fire\ temperature\ in\ ^{\circ}\mathrm{C}$$
$$t = time\ in\ hr, t \le \frac{0.08}{F}+1$$
$$F = opening\ factor\ in\ m^{1/2}, 0.01 \le F \le 0.15$$
$$C = a\ constant\ to\ account\ for\ boundary\ materials$$

For short duration-high intensity fire, it was assumed that opening factor $F = 0.15\ m^{1/2}$ and boundary material constant $C = 1.0$ for light material. At 0.75 hour, it was assumed that the fire stopped burning, and the air temperature around the structure started cooling down with a decay rate of 20°C per minute until reaching the original room temperature. For long duration-low intensity fire, the opening factor was set to be $F = 0.02\ m^{1/2}$ and the boundary fuel constant was $C = 1.0$. The fuel ran out after 3 hours, and the temperature started decreasing in the rate of 10°C per minute until reaching 20°C. Both curves can be seen in Figure 8.

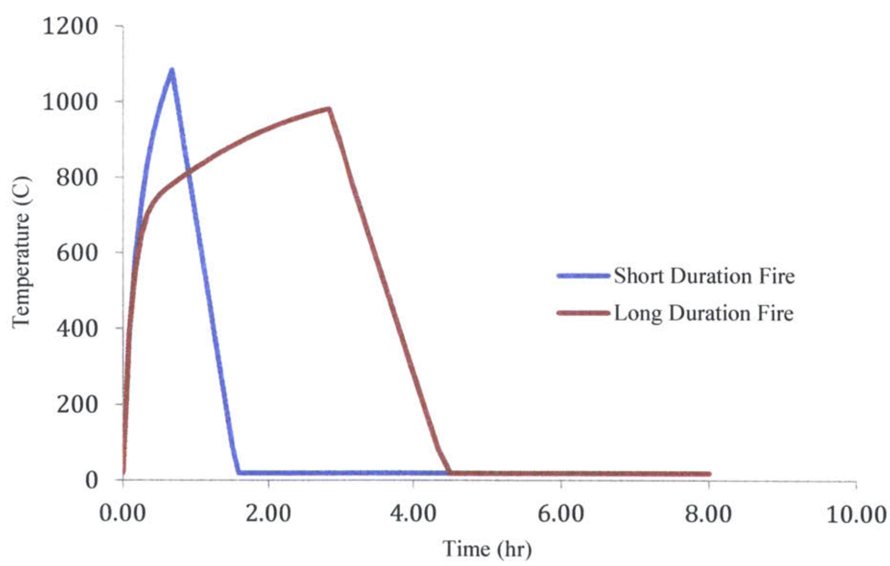
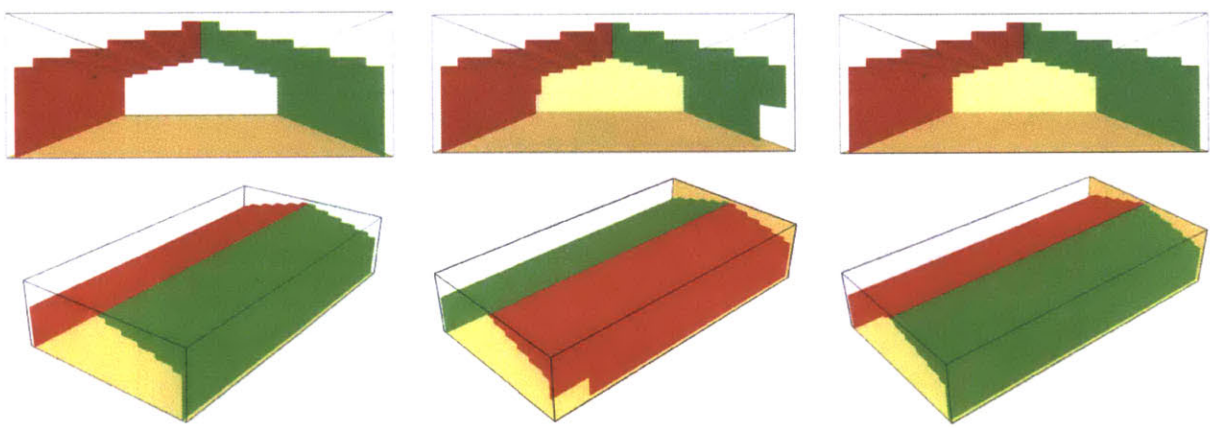


Figure 8: 'Natural' fires

[15] (Lie)

1.2.2 Numerical Analysis – FDS Simulation

Fire Dynamic Simulator/ Smoke View (FDS/SV) was introduced to serve the purpose of simulating the non-linear behavior of compartment fire. Three cases were adapted. The front and back walls were set to be fully opened in the first scenario to allow continuous air supply through the entire warehouse. In the second case, there were two 10m x 5m openings on the corner of both side-walls to allow limit air ventilation. In this scenario, the opening factor was calculated to be $0.16m^{1/2}$, which was very close to the boundary condition of short duration fire. The inner space of the third warehouse model was completely isolated from the outside environment without air ventilation (See Figure 9). Due to certain constraints, the mesh size of the model was set to 1m x 1m x 1m. The FDS input scripts for each scenario can be seen in Appendix B.



a) b) c)

Figure 9: FDS models a) open warehouse b) two-door open warehouse c) fully closed warehouse

With the developed model of each study case, a few assumptions were made to identify the location and intensity of the fire. It was restricted to a 1m x 10m rectangular section located in the middle of the warehouse, and the Heat Release Rate per Unit Area (HRRPUA) of the fire was set to be a function varying with time, shown below. However, the air in the fully closed warehouse would be burnt out rather quickly with this heat release rate, so the HRRPUA value of it was set to be $500kW/m^2$ instead.

$$HRRPUA(kW/m^2) = \begin{cases} 0, & t = 0 \\ 13000, & t = 500 \\ 34000, & t = 1000 \end{cases}$$

Five sensors were placed to monitor the air temperature at the surface of the structure: the first one located on top of the fire to record fire temperature, the second one located at the apex of the room, the third one located where the highest positive bending moment occurred on the roof beam, the fourth one located near the roof beam at the fixed connection between the roof beam and column, and the last one located at the same place but closer to the column. The green dots in Figure 10 are the temperature sensors. Those air temperature data would later be used to analyze the performance of structural members at different locations, and identify the point of failure. The selected temperature data can be found in Appendix A. Figure 12, Figure 13 and Figure 14 are the time-temperature curves gathered with those sensors in each warehouse. Since the temperature data recorded from the fourth and fifth sensors were identical, only one of the two was shown in the graph.

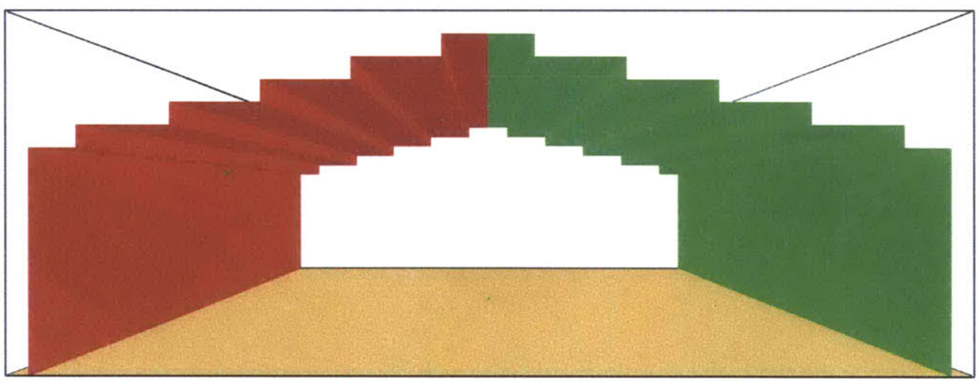


Figure 10: Locations of the temperature sensors

Comparing the time-temperature curves for analytical and numerical methods, the fire temperature recorded from an open warehouse has a strong agreement to the ASTM E119 standard temperature curve. Also, the curves of short duration and two-door open have relatively close temperature increase rates at first 5 minutes of heating. However, in the two-door open case, the temperature drops significantly as soon as it hits 900°C. The animation generated by FDS gives a clear explanation to that phenomenon. Instead of staying at its original location, the fire propagates toward the two openings for more air source, and eventually relocated at the two openings (see Figure 11). In a fully closed warehouse, the fire temperature drops at 45 minutes, when the air was completely burnt out.

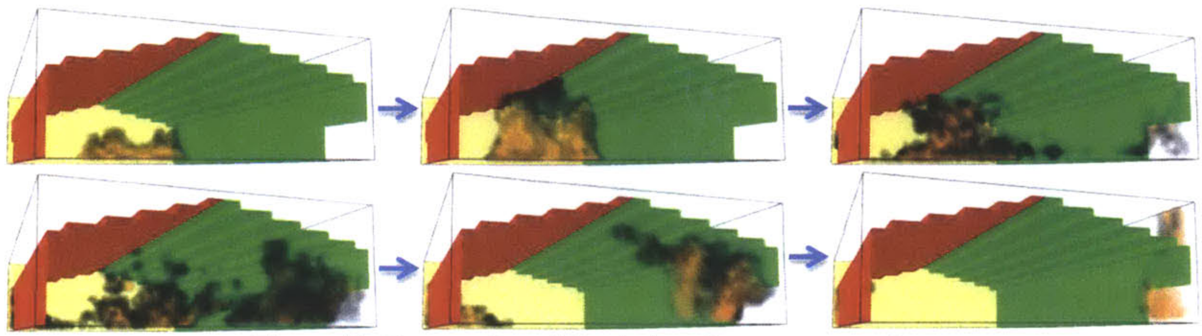


Figure 11: Propagation of fire in two-door open warehouse

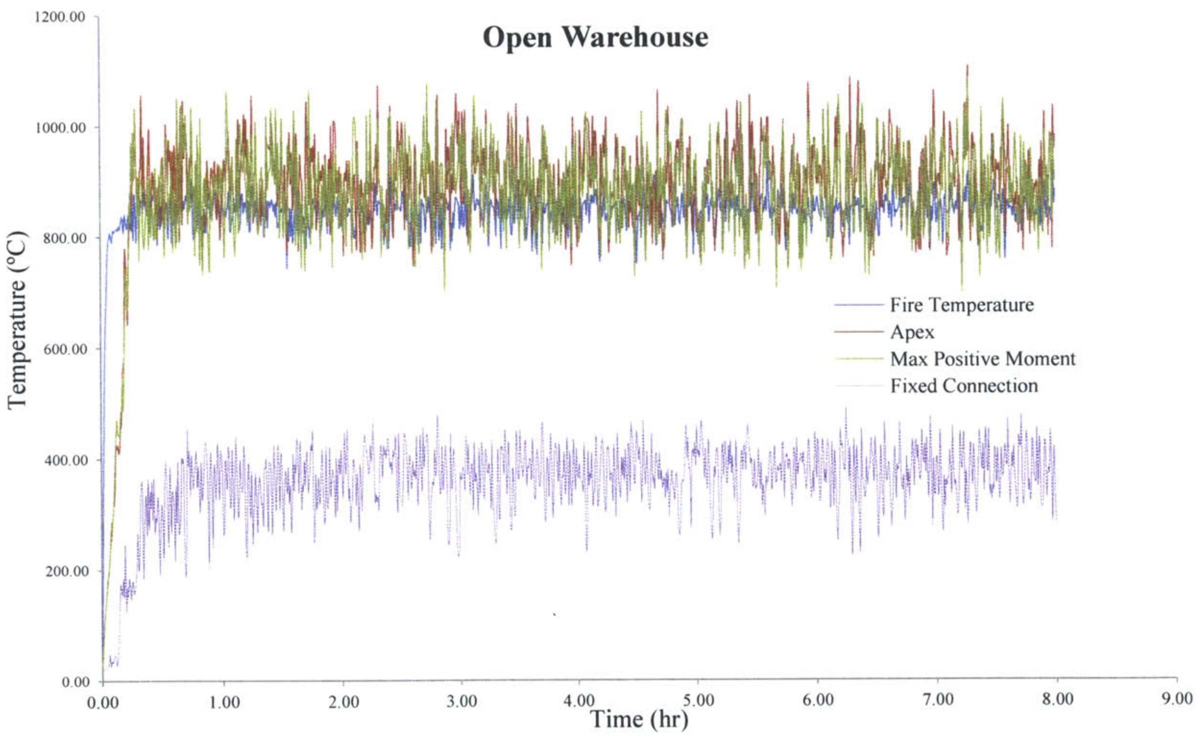


Figure 12: Open Warehouse Temperature

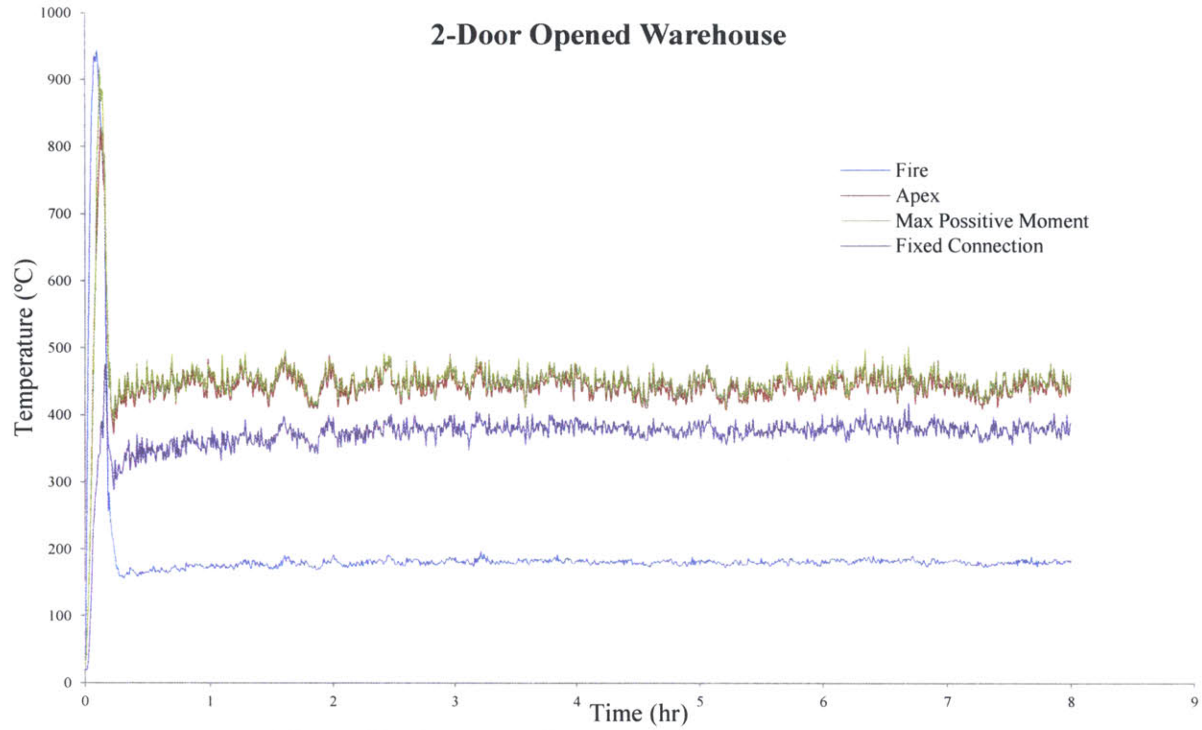


Figure 13: Two-Door Opened Warehouse Temperature

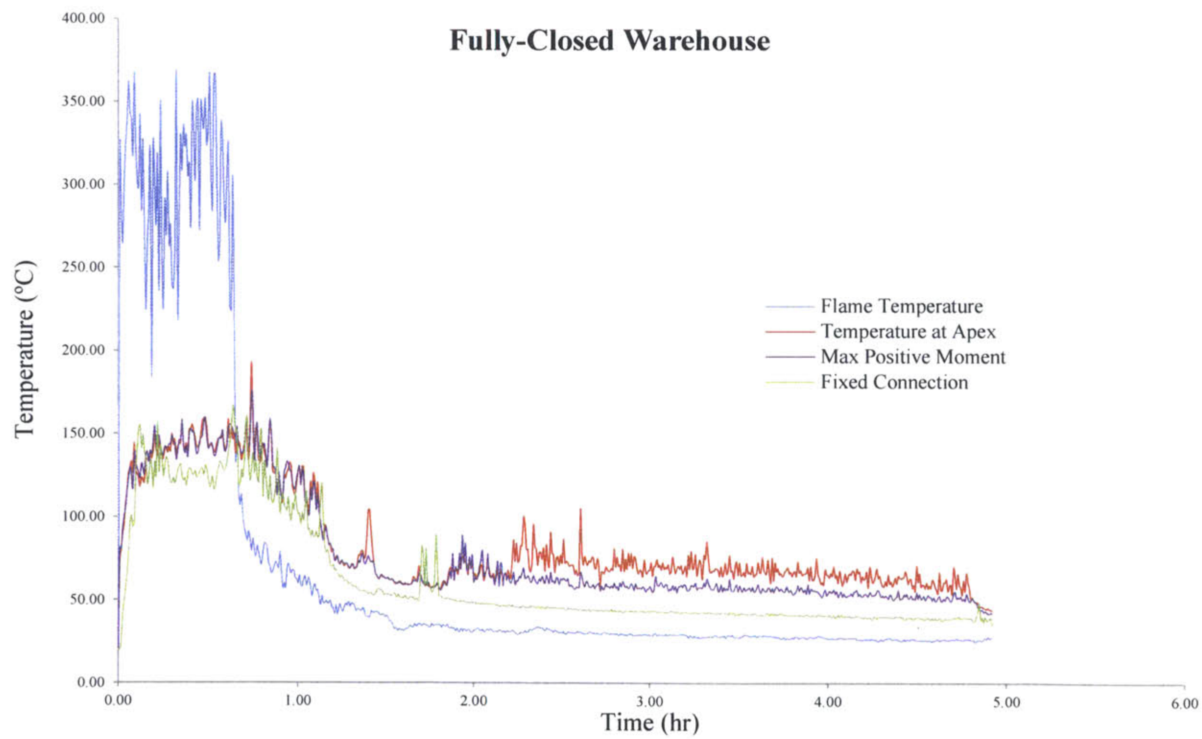


Figure 14: Fully Closed Warehouse Temperature

2 Analysis

2.1 Warehouse Design

The size and structural system of the warehouse are predefined in Section 1.1. The warehouse is designed to be located in Boston, Massachusetts. According to ASCE 7-10[16], because the angle of the roof is 14 degrees, the warehouse's mean roof height, h, is 12.5m, and the length of the roof beam on each side is calculated to be 20.616m. This warehouse is assumed to store products that are toxic and will pose a serious threat to the public if released. Based on Table 1.5-1 in ASCE 7-10, the warehouse is rated IV on Risk Category. Because of its location, this warehouse falls into Category B for surface roughness, and with its mean roof height, it is also under Category B for exposure (details can be found in ASCE 7-10, Section 26.7.2 and 26.7.3).

2.1.1 Loading Criteria[17]

Table 4: Design loads

Design Loads kN/m	
Dead Load	
	0.63
Live Load	
	2.88
Snow	
Windward Roof	1.61
Leeward Roof	9.49
	5.38
Wind	
Windward Wall	2.86
Windward Roof	-3.78
Leeward Wall	-2.74
Leeward Roof	-2.68

2.1.1.1 Dead Load & Live Load

The warehouse is a one story structure. The source of dead load applied on the frame is the roofing material's weight and structural member's self-weight. The roof consists of three different layers: a layer of 18-gage metal decking on the top, then a layer of water proofing of

[16] (ASCE)
[17] All data in Section 2.1.1 are calculated following (ASCE) specification

Single-Ply Sheet, and at the bottom was rigid insulation. In terms of live load, according to ASCE 7-10, Table 4-1, the minimum design live load on the roof should be 0.96kN/m^2 (20psf).

2.1.1.2 Wind Load

In order to determine the accurate wind pressure on the structure, both its location and geometric size are essential factors. Based on Chapter 26 of ASCE 7-10, Boston, has a minimum design wind speed of 63m/s (140mph), and directionality factor K_d is 0.85, with Topographic Factor K_{zt} of 1. Because the mean roof height of the warehouse is 12.5m, it is considered to be a low-rise building. In Chapter 28, Velocity Pressure Exposure Coefficient K_h/K_z was determined to be 0.7 for Category B Exposure. With the equation below (28.3-1, ASCE 7-10), the minimum design Wind Velocity Pressure, q_z/q_h, is defined.

$$Imperial: q_z = 0.00256 K_z K_{zt} K_d V^2 \ (lb/ft^2)$$
$$SI: q_z = 0.613 K_z K_{zt} K_d V^2 \ (N/m^2)$$

Because the warehouse is designed with gable frame, depending on which side of the warehouse is exposed to wind, the wind pressure varies on different sections of the warehouse. Therefore, both the Internal Pressure Coefficient GCpi and External Pressure Coefficient GCpf are determined by using Table 26.11-1 and Table 28.4-1 in ASCE 7-10. GC_{pi} is the enclosure classification factor of the structure, and it is required to be ±0.18 for an enclosed structure. At the same time, GC_{pf} is a coefficient that varies for different exposed sections and the slope of the pitched roof. With equation below (28.4-1, ASCE 7-10), the wind pressure, p, is calculated (see Appendix D).

$$p = q_h\left[\left(GC_{pf}\right) - \left(GC_{pi}\right)\right] \ (lb/ft^2)(N/m^2)$$

2.1.1.3 Snow Load

In the New England region, snow load is another dominating design load that has to be taken into consideration during structural design. Following the instructions given in ASCE 7-10, Chapter 7, the flat roof snow load p_f was calculated with the equation below (7.3-1, ASCE 7-10).

$$p_f = 0.7 C_e C_t I_s p_g \ (lb/ft^2) \ (kN/m^2)$$

$$C_e = Exposure\ Factor, Table\ 7-2, ASCE\ 7-10$$
$$C_t = Thermal\ Factor, Table\ 7-3, ASCE\ 7-10$$
$$I_s = Importance\ Factor, Table\ 1.5-2, ASCE\ 7-10$$

According to Table C7-1 in ASCE 7-10, the recorded largest ground snow load, p_g, in Boston is 39psf, equivalent to 1.867kN/m^2. Because of the pitched roof of the warehouse, the slope factor C_s is used to calculate the snow pressure p_s with the equation below.

$$p_s = C_s p_f$$

$$C_s = Warm/Cold\ \ Roof\ Factor, Section\ 7.4.1/7.4.2, ASCE\ 7-10$$

When wind load and snow load are combined, the warehouse's roof needs to be capable of carrying drifted snow loads. The angle of the roof is among the range that is required to apply unbalanced snow loads and its length is longer than 6.1m. There is an additional load that needs to be added over the rectangular surcharge area on the leeward side of the roof.

2.1.2 Frame Design

All the design procedures in this thesis are following the criteria listed in Load and Resistance Factor Design (LRFD). According to Chapter 2 of ASCE 7-10, the four factored load combinations that are required to design the gable frame are listed below.

$$1.4D$$
$$1.2D + 1.6L + 0.5(L_r\ or\ S\ or\ R)$$
$$1.2D + 1.6(L_r\ or\ S\ or\ R) + (L\ or\ 0.5W)$$
$$1.2D + 1.0W + L + 0.5(L_r\ or\ S\ or\ R)$$

In the SAP2000-11, a 2-D frame model was constructed following the geometry described in Section 1.1 (see Figure 15). In order to apply a pin connection at the crown, the moment at the end of both roof members was released.

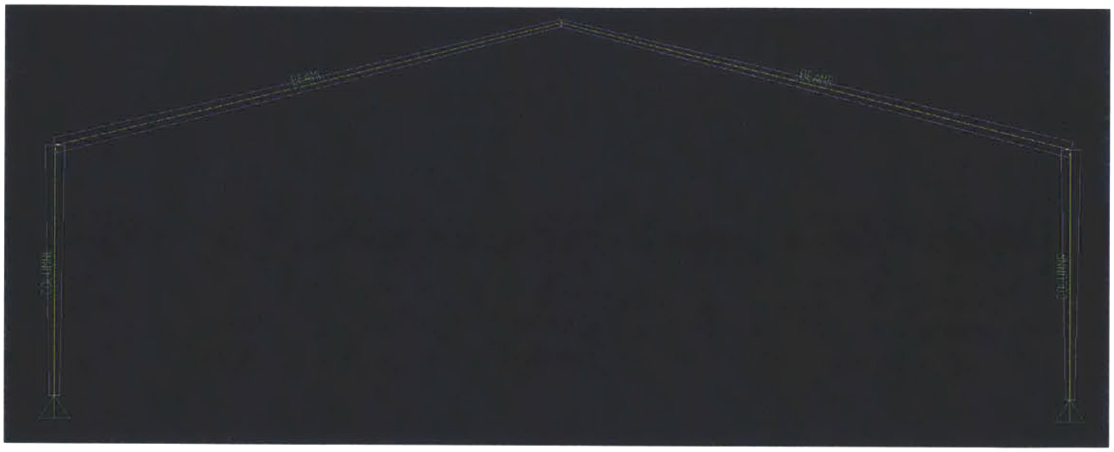


Figure 15: SAP model

Design loads were applied to the frame model with corresponding load combinations, which helped to identify which combination would result in the largest reactions of the structure. The four load combinations given above by LRFD were broken down to seven more detailed combinations, shown below:

$$1.4D$$
$$1.2D + 0.5L_r$$
$$1.2D + 0.5S$$
$$1.2D + 1.6L_r + 0.5W$$
$$1.2D + 1.6S + 0.5W$$
$$1.2D + 1.0W + 0.5L_r$$
$$1.2D + 1.0W + 0.5S$$

After running the analysis with properly assigned loads and load combinations, the resultant forces and moments were gathered and compared, and identified the governing combination as highlighted in Table 5. In order to assure the model and results generated by SAP2000 v11 were accurate, hand calculations were performed with load combinations of $1.2D + 1.6S + L$ and $1.2D + 1.6S + 0.5W$ (See Appendix E). The results from hand calculations were very close to the results given by SAP2000. Therefore, the results from SAP2000 model were reliable. The combination that generated largest reaction in the frame was $1.2D + 1.6S + 0.5W$, and it would be used to design the frame structure.

Table 5: Resultant reactions in the frame generated by SAP2000

	Roof Members				Column			
	Moment	**Shear**		**Axial**	**Moment**	**Shear**		**Axial**
	Fixed End	Crown	Fixed End		Fixed End	Fixed End	Support	
1	117.6	2.85	14.26	15.687	117.6	11.76	11.76	17.64
2	292.8	7.101	35.51	39.06	292.8	29.28	29.28	43.92
3	220.33	5.344	26.72	29.39	220.33	22.03	22.03	33.05
4	564.01	12.74	66.42	68.54	564.01	50.38	62.42	81.06
5	882.96	62.31	124.45	115.93	882.96	82.28	94.31	148.85
6	272.88	4.192	28.58	20.54	272.88	12.99	41.58	32.71
7	173.21	13.092	29.90	10.59	173.21	3.03	31.62	31.57

2.1.2.1 Timber Design

Softwood glulam was used to design the warehouse. Its stress class was 24F-1.8E, and the combination symbol was 24F-E4. Both the core and surface material of it were southern pine, and special tension laminations were also applied. One important factor that would affect the strength of timber material was the moisture content, and it was assumed to be 12%. The strength properties of such glulam were found in Table 5A of 2005 NDS Supplement[18]. According to Table M5.3-1 of 2005 Edition Manual for Engineered Wood Construction[19], and all the strength values were adjusted by corresponding factors. Those design factors' values were mostly found in Donald Breyer's Design of Wood Structures[20], see Appendix F for details.

With all collected data, the required minimum cross-section areas of the beam and column at the fixed end were designed to satisfy the bending moment. Since the moments at crown and supports were zero, both the roof beam and column would be designed into a tapered shape to use the material more efficiently. The roofing materials were able to provide lateral stability to the roof beams, which were considered as fully braced members. However, the columns did not have any lateral constraint. Detailed calculations can be found in Appendix F. Those designed members were imported into the SAP2000 model, and the moments were recalculated to check if they would satisfy the loading conditions with self-weight applied. At last, the serviceability of

[18] (American Forest & Paper Association (AF&PA))
[19] (American Forest & Paper Association (AF&PA))
[20] (Breyer, Fridley and Cobeen)

the roof member was checked to ensure satisfaction of the International Building Code's requirements[21]. Table 6 shows the detailed sizes of individual members.

Table 6: Timber structure members' sizes

	Roof Beam (in.)	Column (in)
Length	811.65	393.70
Width	8.5	8.5
Pinned End Depth	15.13	13.75
Fixed End Depth	49.5	49.5

2.1.2.2 Steel Design

The structural elements in the steel frame were designed with Grade 50 wide flange sections. Following the design procedures that were listed in American Institute of Steel Construction (AISC)[22], the members were designed to satisfy all the minimum stress requirements. Same as the timber design, the steel members were also designed into tapered shape. It was assumed that the smaller end's section depth was half of the bigger end, and all the other dimensions stayed the same.

Similar to the design strategy used in 2.1.2.1, the bigger section of all members were first designed to satisfy the bending moments, and a general steel section was chosen from Table 3-2 of the AISC manual. Because the beams are braced, they did not need to be checked for local buckling, but the columns were required to be designed for inelastic behavior. Table 7 shows the final designed member sizes; see Appendix F for detail calculations.

Table 7: Steel structure members' sizes

	Beam		Column	
	Fixed End	**Crown**	**Fixed End**	**Support**
A (in2)	24.7	18.8305	34.2	25.3645
d (in)	24.1	12.05	30	15
tw (in)	0.47	0.47	0.565	0.565
bf (in)	9.02	9.02	10.5	10.5
tf (in)	0.77	0.77	0.85	0.85

[21] (International Building Council, Inc.)
[22] (American Institute of Steel Construction (AISC))

2.1.2.3 Fireproofed Steel Design

Design of a fireproof steel structure followed the same procedure in 2.1.2.2. In this design, sprayed mineral fibre was used as fireproofing material. It was set to be a 28mm thick to achieve 2-hour fire resistance rating based on the section factor of the steel member, according to Table 2. Because the sprayed mineral fibre was a lightweight material, the additional weight applied on the structure could be ignored.

2.2 Thermal Analysis

In a three-hinged gable frame, formation of one additional plastic hinge would cause its failure. The frame was a symmetric structure with heat source located in the middle between the columns. One could study the performance of either half of the frame, because when both sides were heated in the same way, the hinge would form simultaneously at the same location.

Fire is an unpredictable event and the structure is unlikely be subjected to the maximum design loads used at normal temperature. Therefore, different design codes suggest different combinations to be used. Below is a table concluding such combination specifications. ASCE combinations are used in this thesis. Each half of the frame was simplified to fix-pin supported roof beam and column. Calculation was performed to determine the moment distribution of the frame under the desired design load from Table 8 (See Appendix E).

Table 8: Dead and live load factors for fire design

Design Codes	Dead Load	Permanent Live Load	Other Live Load
New Zealand (SNZ, 1992)	1	0.6	0.4
Eurocode (ECI, 1994)	1	0.9	0.5
USA (ASCE. 1995)	1.2	0.5	0.5
Ellingwood and Corotis (1991)	1	0.5	0.5

During a fire, the increasing of local temperature on a member is fully dependent on the dynamics of the fire. For the analytical analysis, it is assumed the member would be evenly heated with the same time-temperature curve. For the numerical analysis, the member is exposed to different temperatures at different locations based on the simulation results. Figure 16 shows that the variation of temperature at different locations is rather large. Instead of having radio propagation, the heat travels with the rising smock, and the temperature directly above the fire is the highest.

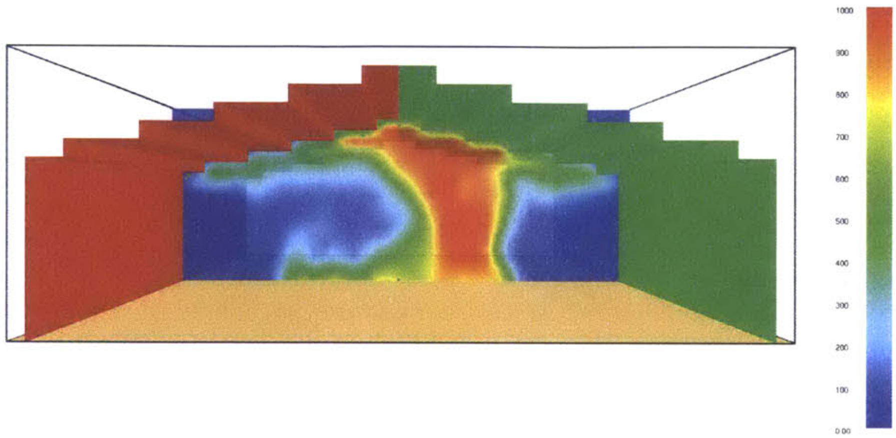


Figure 16: Temperature profile in the middle of the warehouse at t=9820sec FDS

2.2.1 Timber Structure

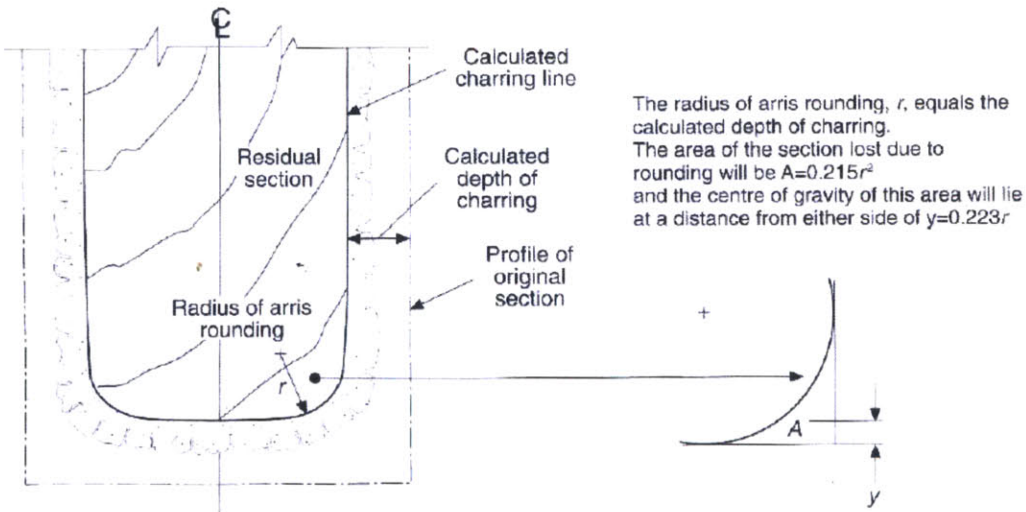


Figure 17: Residual cross section of timber beam exposed to fire[23]

The material used for the timber structural design is southern pine, which is considered one of the softwood species. According to Table 9, the charring rate is 0.7mm/minute for softwood timber. However, the furnace tests conducted at the University of Canterbury suggested that under the same fire exposure, the charring rate was different for the sides of the glulam and the

[23] (Buchanan)

bottom[24]. Therefore, the nominal charring rates[25], β_n, of 0.66mm/minute for sides and 0.57mm/minute for the bottom were chosen as concluded in the report.

Table 9: Charring rates for design[26]

Material	Minimum density (kg/m^3)	Char rate β (mm/minute)	Char rate β_1 (mm/minute)
Glue-laminated softwood timber	290	0.64	0.7
Solid or glue-laminated hardwood timber	450	0.5	0.55
Softwood panel products(plywood, particle board) minimum thickness 20 mm	450	0.9	

Many existing documents that relate to timber's fire rating suggest using the equations below to calculate the char thickness on the timber for standard fire and real fire, and the corner rounding is also taken into consideration as presented in Structural Design for Fire Safety[27] to accommodate the losing material at the corner of the timber, as shown in Figure 17. Because char does not have any strength, only the material left under it is considered to take all the applied loads. Through the equations used for real fire calculation, one can find the air temperature does not affect the performance of timber members; instead, the opening factor of the space and charring rate of the species are the driving factors for defining the char thickness under fire.

Standard testing fire:

$$\beta = 2.58\beta_n / t^{0.187}$$
$$c = \beta t$$
$$k_f = 1.0 - 1/g(A_r/p)$$

$$c = Char\ layer\ thickness\ (mm)$$
$$k_f = Strength\ reduction\ factor\ for\ heated\ wood$$
$$g = Char\ parameter, 200\ for\ bending, 125\ for\ compression,$$
$$330\ for\ tensile\ strength\ and\ modulus\ of\ elasticity$$
$$A_r = Cross\ section\ area\ reduced\ by\ fire\ (mm^2)$$
$$p = Perimeter\ of\ fire\ exposed\ cross\ section\ (mm)$$

[24] (Tsai)
[25] Charring rate measured after 1 hour of fire exposure (Buchanan)
[26] (Buchanan)
[27] (Buchanan)

Design for real fire:

$$\beta_{par} = k_p \beta$$
$$k_p = 1.5(5F - 0.04)/(4F + 0.08)$$
$$c = 2\beta_{par} t_o$$

$$\beta_{par} = Initial\ charing\ rate\ (mm/minute)$$
$$k_p = Parametric\ char\ factor$$
$$F = Opening\ factor\ (m^{1/2})$$
$$c = Total\ thickness\ of\ char\ at\ the\ end\ (mm)$$
$$t_o = Exposure\ time\ to\ fire\ (minute)$$

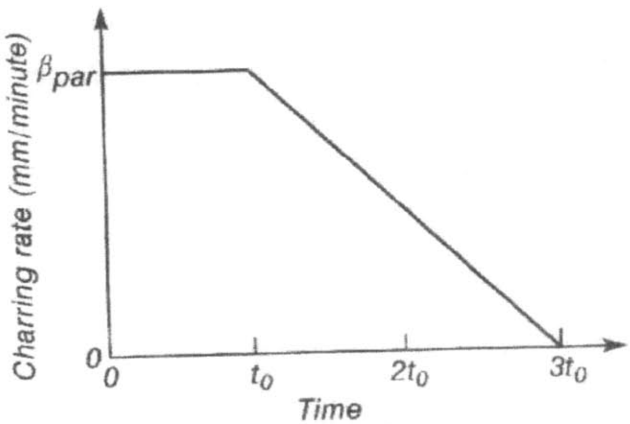


Figure 18: Charring rate with time for parametric fire exposure[28]

As shown in Figure 18, the charring rate does not stop when the fire is dead off at t_o during a real fire. Instead, the timber is still burning under the char layer, and this after effect forms the same amount of char as it does during the exposure. With the char thickness calculated at each time step, the residual cross-sectional area and elastic section modulus of the timber member was calculated. With those values, timber's bending capacity and compression capacity were defined at different time steps. The failure time of the timber would be when those capacities drop below the design fire load, and the ratio of combined load exceeds 1. Appendix G shows a summarized table for rating the timber structure.

[28] (Buchanan)

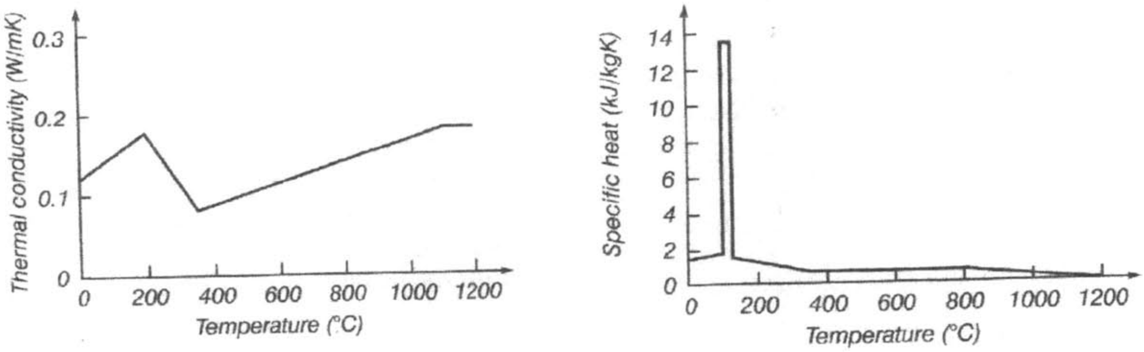


Figure 19: a) Variation of thermal conductivity of wood with temperature, b) Variation of specific heat of wood with temperature[29]

As an organic material, timber's behavior in elevated temperature is nonlinear; both its thermal conductivity and specific heat varies heavily with temperature. Two driving factors for this phenomenon are the dynamic of moisture content in the wood and the thermal decomposition reaction of the wood. Because of that, some material properties are changing correspondingly, such as its thermal conductivity and specific heat. In Figure 19, the thermal conductivity raises after the temperature reaches 300°C, when the char is formed, and the specific heat spikes up to almost 14kJ/kgK because of the evaporation and movement of the moisture content. In order to find a relationship between the elevating temperature of the environment and the changing thickness of the char, a numerical finite element analysis was performed with ANSYS (see Figure 20).

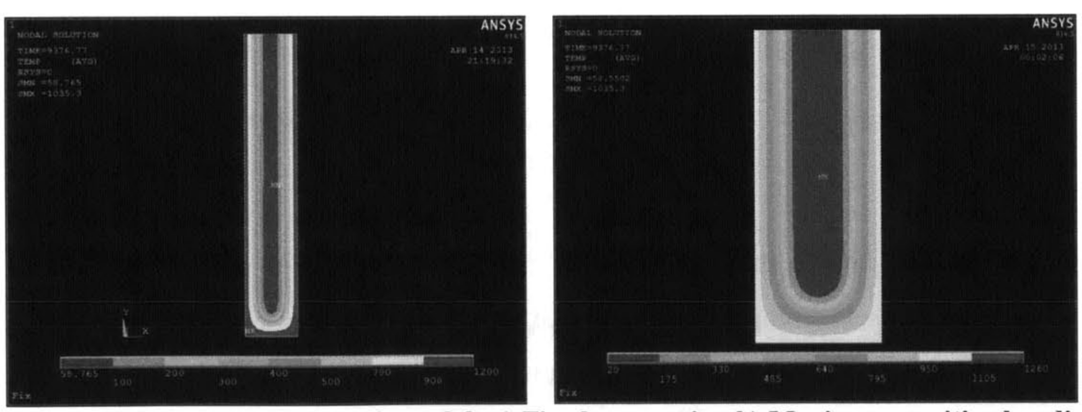


Figure 20: Finite element analysis models a) Fixed connection b) Maximum positive bending moment

[29] (Buchanan)

2.2.2 Steel Structure

Steel has high thermal conductivity, so heat is able to transfer through the entire cross section at a relatively fast rate. The steel structural members used to design the warehouse is a W shape that has thin flange and web plates, which makes it even faster for heat to propagate across the entire cross section, and the temperature variation at different location is very small. Therefore, instead of building a finite element model to define the insignificant temperature difference, it is safe and conservative to assume the temperature on each cross section is the same. The equations[30] below were used to define the temperature of the unprotected steel. Time step used for calculating steel temperature during standard fire and lab generated 'natural' fires was set to be 100s. However, for the temperature data gathered from FDS results, the time step was automatically calculated by FDS when it was simulating the dynamics of compartment fires.

$$\Delta T_s = \frac{F}{V}\frac{1}{\rho_s c_p}\{h_c(T_f - T_s) + \sigma\varepsilon(T_f^4 - T_s^4)\}\Delta t$$

$$c_p = \begin{cases} 425 + 0.773T_s - 1.69 \times 10^{-3}{T_s}^2 + 2.22 \times 10^{-6}{T_s}^3, & 200°\text{C} \leq T_s < 600°\text{C} \\ 666 + 13002/(738 - T_s), & 600°\text{C} \leq T_s < 735°\text{C} \\ 545 + 17820/(T_s - 731), & 735°\text{C} \leq T_s < 900°\text{C} \\ 650, & 900°\text{C} \leq T_s < 1200°\text{C} \end{cases}$$

$$\Delta T_s = Changing\ in\ steel\ temperature(°\text{C}, K)$$
$$F/V = Section\ factor\ (1/m)$$
$$\rho_s = Density\ of\ steel\ (kg/m^3)$$
$$c_p = Specific\ heat\ of\ steel\ (J/kgK)$$
$$h_c = Convective\ heat\ transfer\ coefficient\ (25\ W/m^2K)$$
$$T_f = Air\ temperature, average\ air\ temperature\ of\ each\ time\ step\ (K)$$
$$T_s = Steel\ temperature\ (K)$$
$$\sigma = Stefan - Boltzmann\ constant\ (56.7 \times 10^{-12} kW/m^2K^4)$$
$$\varepsilon = Resultant\ emissivity\ (0.5)$$
$$\Delta t = Time\ step\ (s)$$

As shown in equations above, the specific heat value of steel varies with temperature. Besides the specific heat, the yield strength and modulus of elasticity decreases significantly as temperature increases as well. This is the reason why steel performs poorly in elevated temperature. In order to find the failure time of the steel member, it is necessary to define those properties at each time step under elevated temperature. Since steel does not lose material during

[30] (Buchanan)

fire like timber, the cross section area and elastic section modulus remain the same. The equations[31] below were used to define the yield strength of steel in elevated temperature.

$$E_T = k_{E,T}E_{20}$$
$$k_{E,T} = f(x) = \begin{cases} 1.0 + T_s/[2000\ \ln(T_s/1100)], & 0 < T_s \leq 600°\text{C} \\ 690(1 - T_s/1000)/(T_s - 53.5), & 600 < T_s \leq 1000°\text{C} \end{cases}$$

$$E_T = The\ modulus\ of\ elasticity\ at\ elevated\ temperature$$
$$E_{20} = The\ modulus\ of\ elasticity\ of\ steel\ at\ 20°\text{C}$$
$$k_{E,T} = Ratio\ of\ changing\ E_T$$

2.2.3 Protected Steel Structure

With 28mm of sprayed mineral fibre coating the steel member, it is expected to reach the 2-hour fire rating according to Table 2. The thermal conductivity k_i of it is 0.12W/mK and specific heat ci equals 1200J/kgK. As with the unprotected steel, the steel temperature under fireproofing could also be considered to be the same across the cross section, but the temperature calculation of the steel has to be taken into consideration with the insulation, see Equation[32] below.

$$\Delta T_s = \frac{F}{V}\frac{k_i}{d_i\rho_s c_s}\frac{\rho_s c_s}{\rho_s c_s + (F/V)d_i\rho_i c_i/2}(T_f - T_s)\Delta t$$

$$\rho_i = Density\ of\ the\ insulation\ (kg/m^3)$$

The same procedures in 2.2.2 were used to define the fire rating of the protected steel structure.

[31] (Buchanan)
[32] (Buchanan)

3 Results

Table 10 is a summarization of the failure times of all three study cases under different fire scenarios. As mentioned in the introduction, the unprotected steel structure has a very poor performance under elevated temperature. With lab testing fire temperature, the member fails between 6 and 12 minutes at the fixed connection between roof beam and column, and the location where the beam is subjected to the highest positive moment does not fail until a much later time, between 26 and 127 minutes. During the open compartment fire simulated by FDS, the steel structure only failed during open fire at the location under maximum positive bending moment at 18 minutes, and does not fail for the others.

Timber structures fail much later than the steel structure does, between 1 and 3 hours at the fixed connection during numerical analysis. However, according to the results suggested by finite element analysis, the timber structure fails at 2.5 hours at fixed connection under standard fire exposure, and 5 hours at the point of maximum positive moment under open compartment fire. For the rest of the fire loading, the timber structure does not fail.

Table 10: Failure time of structures under different fires

	Failure Time (min)							
	Timber				Unprotected Steel		Protected Steel	
	Fix	Comb	Max Positive Moment	Comb	Fix	Max Positive Moment	Fix	Max Positive Moment
Numerical								
Standard	90	100	130	130	6.67	66.67	178.33	nf
Short	70	75	105	105	10	26.67	nf	nf
Long	180	200	250	250	11.67	126.67	nf	nf
Open					nf[33]	17.76	nf	nf
Semi					nf	nf	nf	nf
Closed					nf	nf	nf	nf
Finite								
Standard	212		250					
Short	nf		nf					
Long	nf		nf					
Open	nf		303					
Semi	nf		nf					
Closed	nf		nf					

[33] nf = did not fail during the test

3.1 Timber Structure

Figure 21 and Figure 22 below show the relationship between time and capacity ratio of the timber structure.

The first plot was the result from the analytical analysis, where all the cases failed at certain point. In the second plot however, only three lines reached the failure zone while the rest stopped when the environment temperature started dropping. The main reason behind that was, during finite element analysis, the after-burn under the char layer was not taken into consideration. The temperature of the timber decreased with the applied temperature. The other thing that happened during the analysis was that the physical and thermal properties of timber also recovered back to the initial values, which had a huge effect on the final result. In other words, when the timber temperature dropped below 300 ºC, instead of staying in the form of char, it returned back to timber.

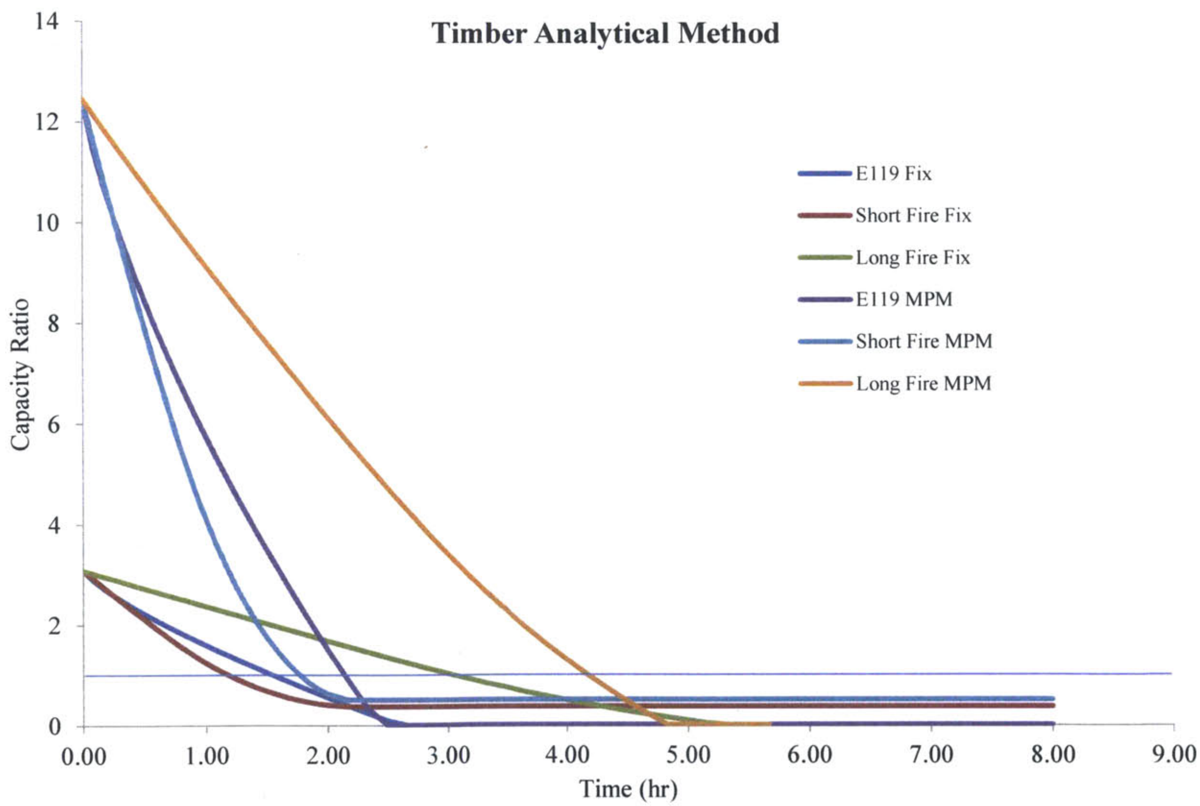


Figure 21: Timber performance - analytical method

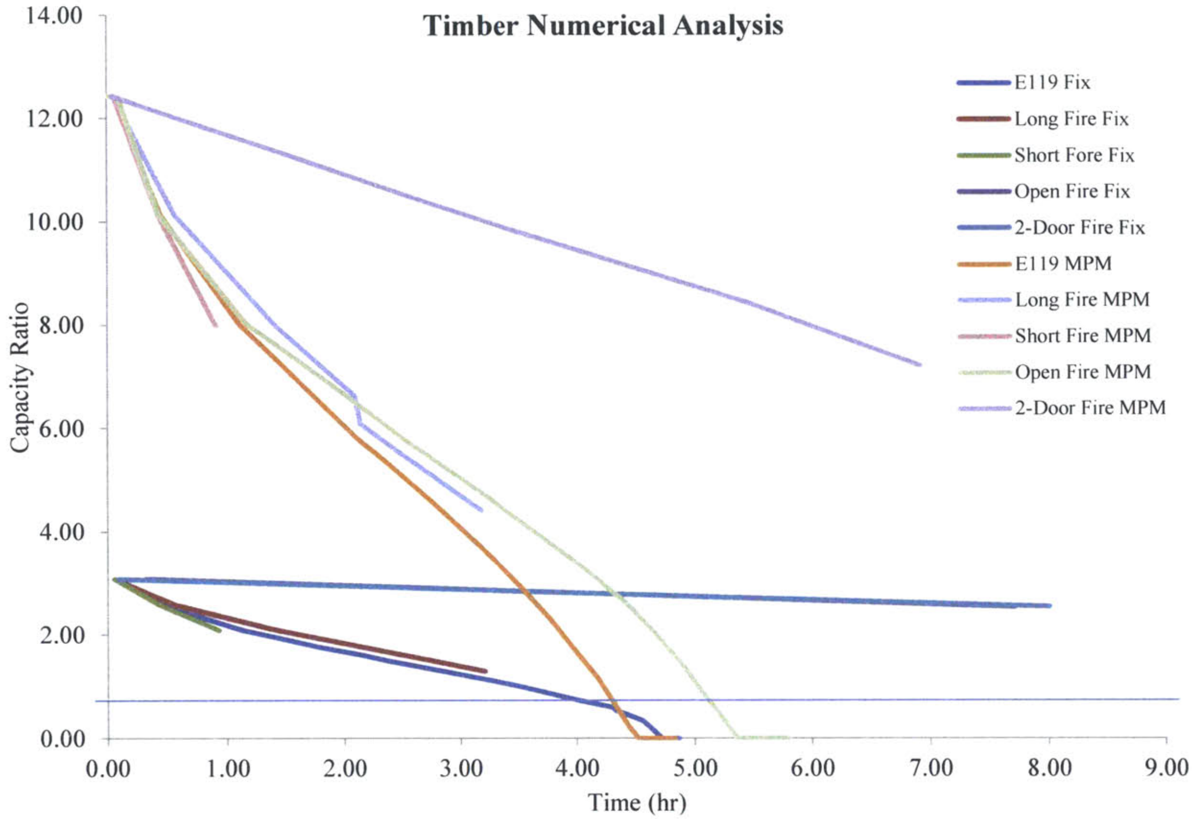


Figure 22: Timber performance - numerical analysis

3.2 Steel Structure

Figure 23 and Figure 24 display the capacity variation of the steel structure during both lab testing fire and compartment fire.

During lab fire, all the members failed at the fixed connection first, while during compartment fire, only the beam subjected to open fire failed at maximum bending moment location. First, it could be proven that unprotected steel structure performed poorly under elevated temperature; it could not withstand the temperature over half an hour. Unless extra redundancy was introduced to the location where the largest bending moments was at, which would give it a higher fire rating.

When it was subjected to compartment fire, the member only failed during open fire at the maximum positive moment. Based on the temperature curves recorded at different locations, at the fixed connection, the temperature was actually much lower than it was directly above the fire source, which caused the steel temperature to increase faster than the fixed connection.

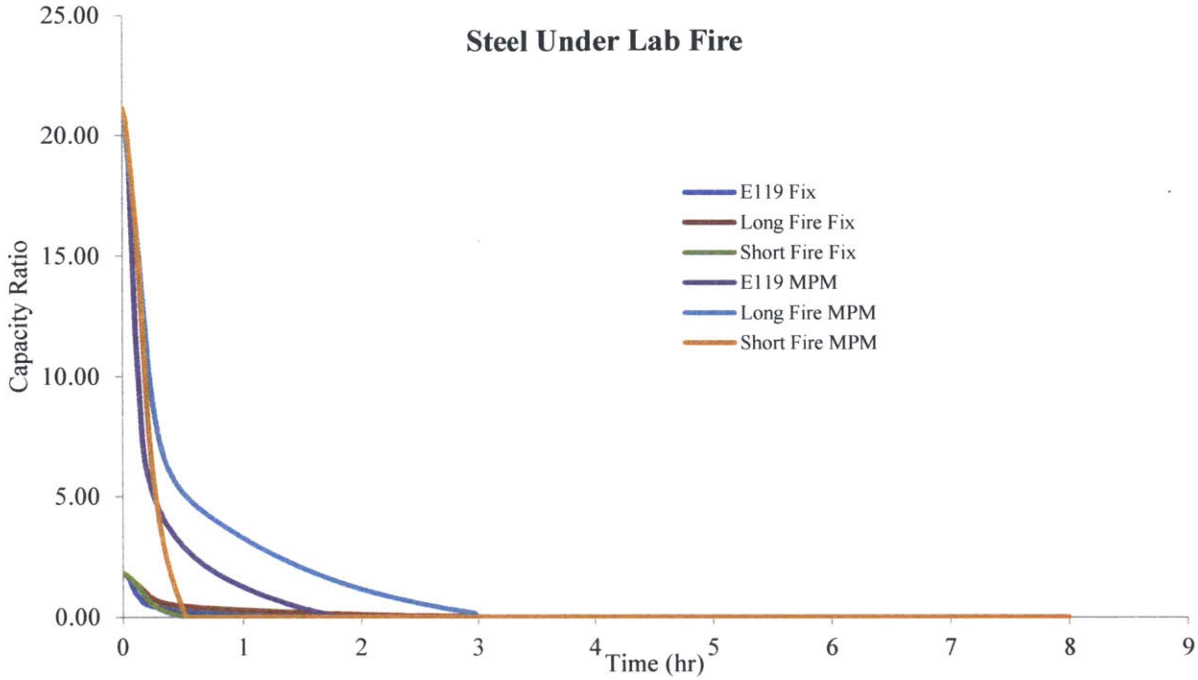


Figure 23: Performance of unprotected steel under lab fire

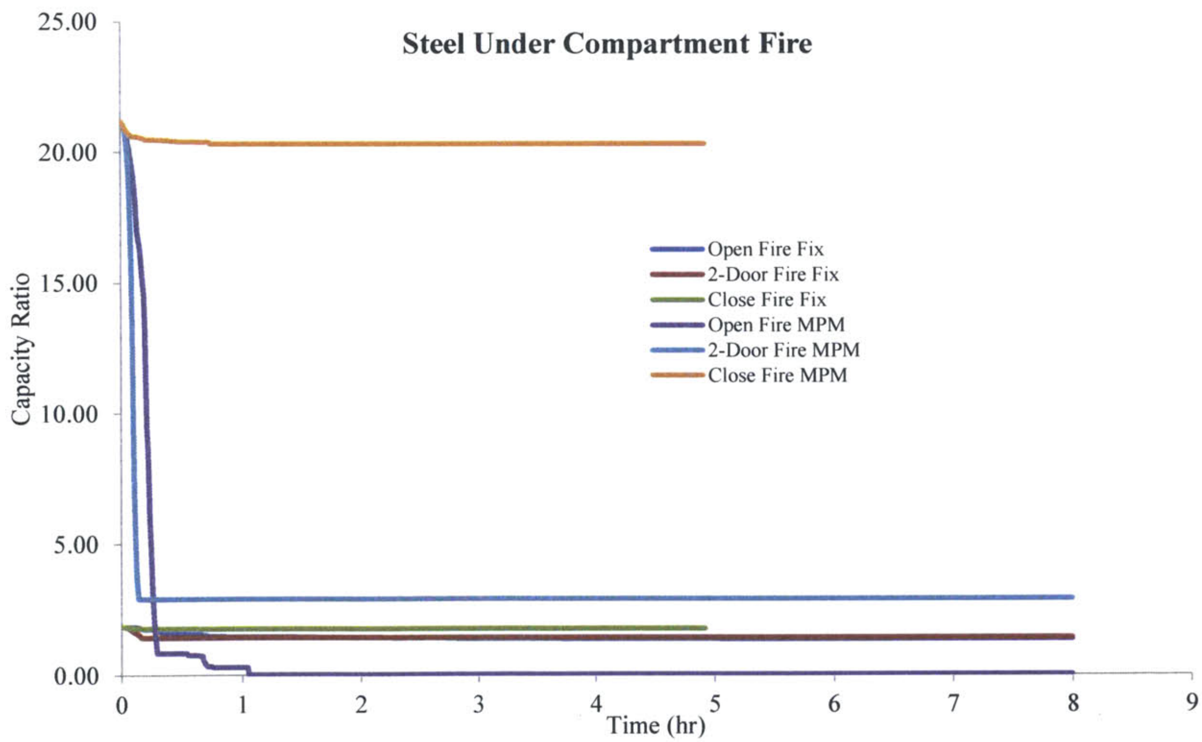


Figure 24: Performance of unprotected steel under compartment fire

3.3 Protected Steel Structure

Figure 25 and Figure 26 show the performance of protected steel during elevated temperature, and the behavior is much different than unprotected steel.

For the protected steel case, the plastic hinge only formed once at maximum positive moment during ASTM E119 standard testing fire. In the rest of the study cases, the capacity was either sufficient through 8-hour heating or recovered as the steel itself started cooling down. When the steel temperature started decreasing, it would regain its strength and, in theory, it would reach its maximum strength before the fire. When the member was subjected to 'natural' fire simulated in lab, the deduction of steel yielding strength and increment of temperature were so small, as soon as the air temperature started decreasing, the steel was able to regain its capacity.

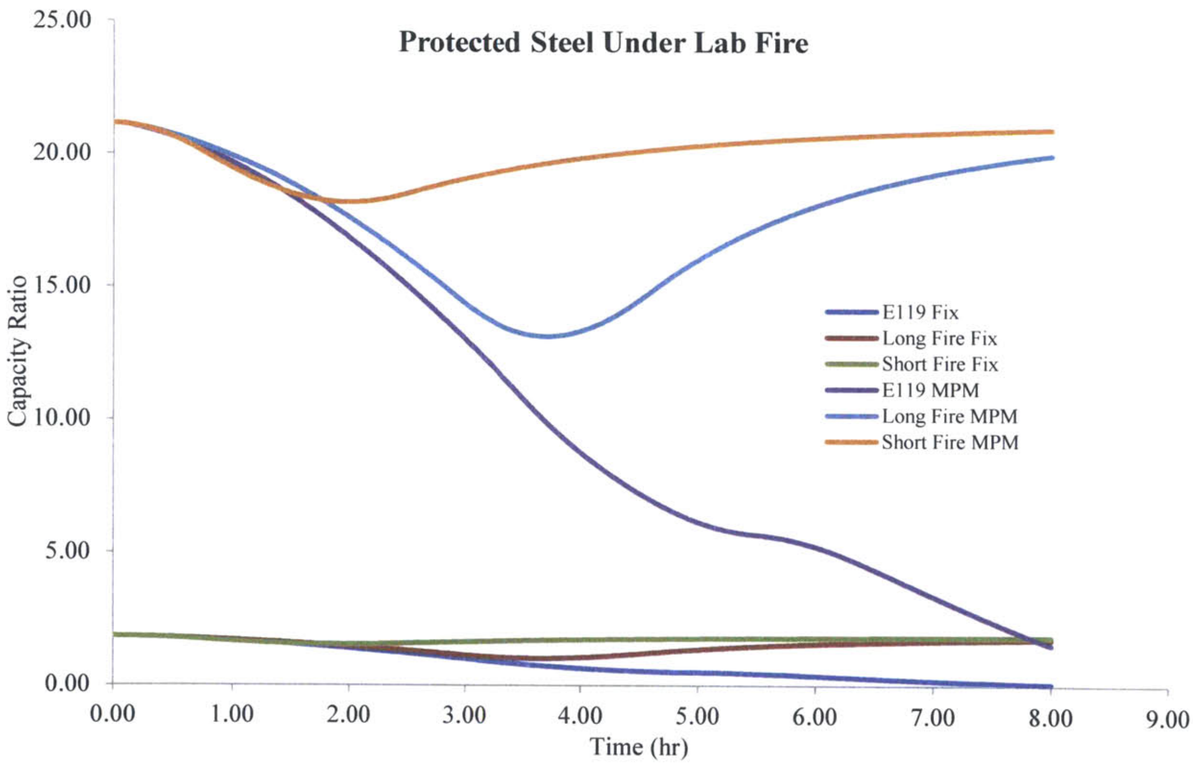


Figure 25: Performance of protected steel under fire

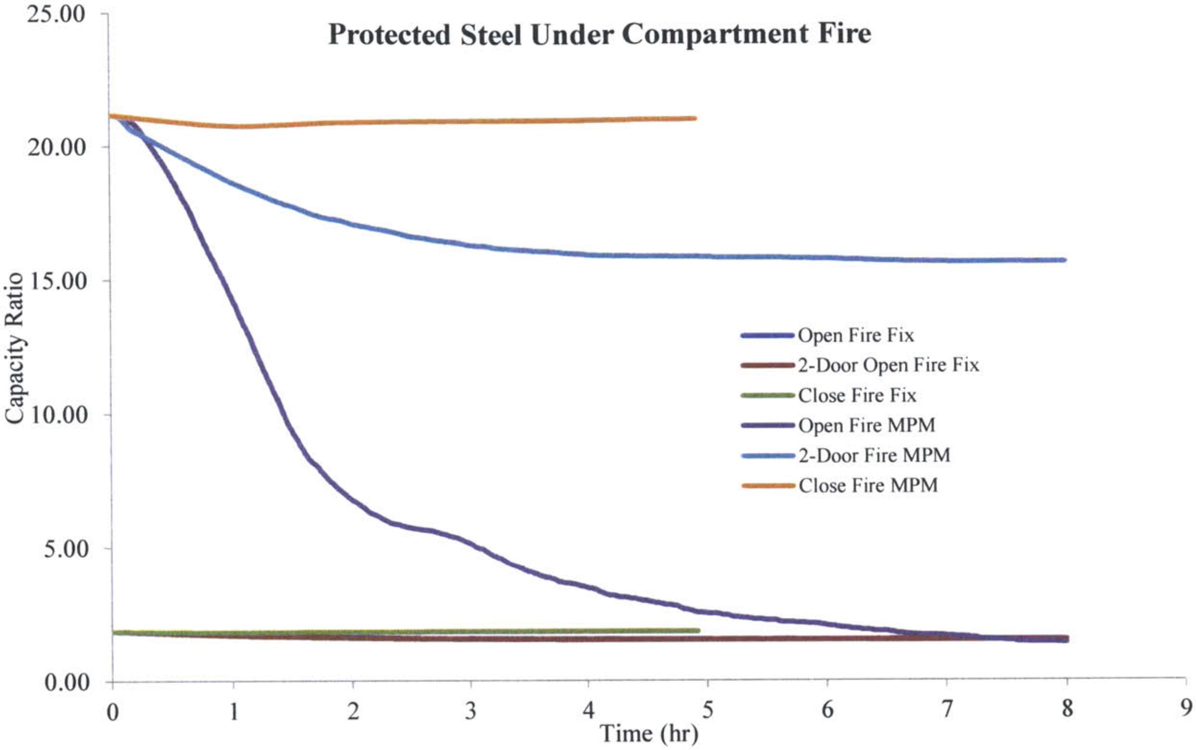


Figure 26: Performance of protected steel under compartment fire

4 Discussion (future analysis)

4.1 Cost

From the results, one could easily identify that steel structure with sprayed on fire proofing has the best performance. However, many other external factors decide whether or not it is the most feasible material to use. The first and most important one is the cost, not only the construction cost, but also the maintenance cost throughout the years along with restoration cost after any fire events. Of course, the unprotected steel structure will not be taken into consideration due to its poor fire performance.

The price per unit weight of glulam is much lower than steel, and the timber structure is also lighter in weight. On top of that, additional work is required to apply spray-on fireproof material to steel structure. This procedure has to be done on-site, because it needs to be fully covered including all the connections, which adds further on-site construction cost. Therefore, the timber structure proposes a much more economical solution for low initial and construction cost.

In comparison to the protected steel structure, the timber structure suffers much more physical damages in a fire, because large amount of material is burnt and the structural members lose their cross sectional areas permanently. On the other hand, the steel structure is able to recover its strength when the temperature is dropped. However, whether or not they would be able to serve at full capacity, as they were before the fire, is based on certain circumstances: the members do not exceed the allowable deflections, or no physical damages applied to them. Each member needs to be inspected and fireproof material must be reapplied if necessary. In comparison, it is required to replace any timber member that suffered any physical damages in fire.

In conclusion, for the warehouse used in this study that stores highly flammable and toxic materials, the protected steel structure will be the more cost-effective approach, because it has a much higher possibility of catching on fire. However, for those other warehouses that store low fire risk products, it will be more reasonable to use a timber structure.

4.2 Fire Protection in Structural Design

Fire protection engineering is a separate discipline from structural engineering, their studies focus on material behavior under controlled circumstances. When it is necessary to identify the dynamic and temperature of a compartment fire, the computational power and time required is rather high. One simulation can take days to finish. For structural engineers, such approach is not recommended even though the results are fairly accurate. However, the results concluded above suggest that, with conventional equations, a structure's fire ratings are over conservative for few study cases.

In this study, the fire is assumed to be located originally in the middle of the warehouse, and the highest temperature zone is right above the fire according to the temperature profile generated by FDS (see Figure 27). In those numerical models, the effects of fire propagation in the warehouse are not addressed. If that was taken into consideration and allows fire to start at a different location, the fire rating of the warehouse would be changed drastically, especially if the ignition happened near the columns.

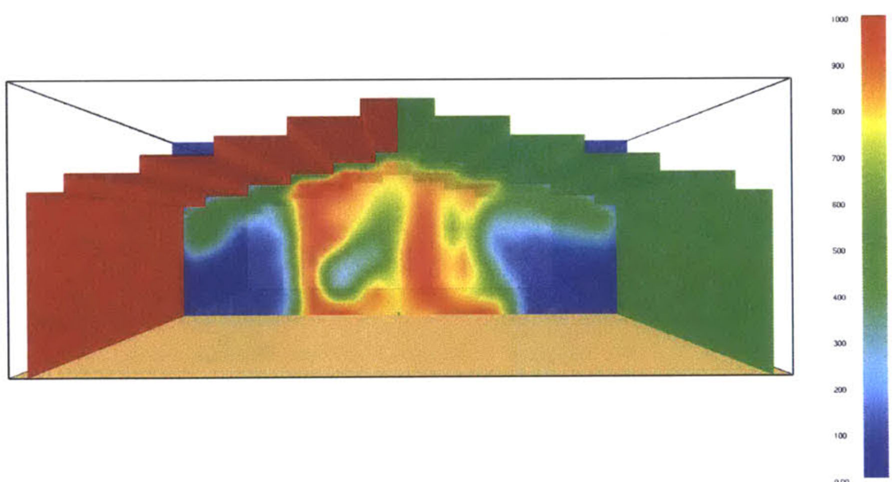


Figure 27: Temperature profile

In further studies, on top of looking at the fire performance of a structure, one should also look at how to optimize a structural system for fire resistance purposes. Some studies have been done on investigating and developing alternative load paths to prevent total collapse of the building if any member fails during fire. Extra redundancy on members should be prevented. Therefore, the fire protection engineer should work closely with the structural engineer to develop more efficient building systems.

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Appendix A Air Temperature Data

Time		ASTM E119			Short Duration Fire			Long Duration Fire		
		Temperature			*Temperature*			*Temperature*		
(min)	(hr)	(°F)	(°C)	(°K)	(°F)	(°C)	(°K)	(°F)	(°C)	(°K)
0	0.00	68	20	293.15	68	20	293	68	20	293
5	0.08	1000	538	810.93	718	381	654	733	390	663
10	0.17	1300	704	977.59	1098	592	865	1027	553	826
15	0.25	1399	759	1032.59	1357	736	1009	1201	649	922
20	0.33	1462	794	1067.59	1545	841	1114	1297	703	976
25	0.42	1510	821	1094.26	1690	921	1194	1353	734	1007
30	0.50	1550	843	1116.48	1806	986	1259	1390	754	1028
35	0.58	1584	862	1135.37	1904	1040	1313	1417	770	1043
40	0.67	1613	878	1151.48	1986	1086	1359	1440	782	1056
45	0.75	1638	892	1165.37	1806	986	1259	1462	794	1067
50	0.83	1661	905	1178.15	1626	886	1159	1482	806	1079
55	0.92	1681	916	1189.26	1446	786	1059	1502	816	1090
60	1.00	1700	927	1199.82	1266	686	959	1521	827	1100
65	1.08	1718	937	1209.82	1086	586	859	1540	838	1111
70	1.17	1735	946	1219.26	906	486	759	1558	848	1121
75	1.25	1750	954	1227.59	726	386	659	1576	858	1131
80	1.33	1765	963	1235.93	546	286	559	1593	867	1140
85	1.42	1779	971	1243.71	366	186	459	1609	876	1149
90	1.50	1792	978	1250.93	186	86	359	1625	885	1158
95	1.58	1804	984	1257.59	68	20	293	1640	894	1167
100	1.67	1815	991	1263.71	68	20	293	1655	902	1175
105	1.75	1826	997	1269.82	68	20	293	1669	909	1183
110	1.83	1835	1002	1274.82	68	20	293	1682	917	1190
115	1.92	1843	1006	1279.26	68	20	293	1695	924	1197
120	2.00	1850	1010	1283.15	68	20	293	1707	931	1204
130	2.17	1862	1017	1289.82	68	20	293	1730	943	1217
140	2.33	1875	1024	1297.04	68	20	293	1751	955	1228
150	2.50	1888	1031	1304.26	68	20	293	1769	965	1238
160	2.67	1900	1038	1310.93	68	20	293	1786	975	1248
170	2.83	1912	1044	1317.59	68	20	293	1802	983	1256
180	3.00	1925	1052	1324.82	68	20	293	1622	883	1156
190	3.17	1938	1059	1332.04	68	20	293	1442	783	1056
200	3.33	1950	1066	1338.71	68	20	293	1262	683	956
210	3.50	1962	1072	1345.37	68	20	293	1082	583	856
220	3.67	1975	1079	1352.59	68	20	293	902	483	756
230	3.83	1988	1087	1359.82	68	20	293	722	383	656
240	4.00	2000	1093	1366.48	68	20	293	542	283	556
250	4.17	2012	1100	1373.15	68	20	293	362	183	456
260	4.33	2025	1107	1380.37	68	20	293	182	83	356
270	4.50	2038	1114	1387.59	68	20	293	68	20	293
280	4.67	2050	1121	1394.26	68	20	293	68	20	293
290	4.83	2062	1128	1400.93	68	20	293	68	20	293
300	5.00	2075	1135	1408.15	68	20	293	68	20	293

310	5.17	2088	1142	1415.37	68	20	293	68	20	293
320	5.33	2100	1149	1422.04	68	20	293	68	20	293
330	5.50	2112	1156	1428.71	68	20	293	68	20	293
340	5.67	2125	1163	1435.93	68	20	293	68	20	293
350	5.83	2138	1170	1443.15	68	20	293	68	20	293
360	6.00	2150	1177	1449.82	68	20	293	68	20	293
370	6.17	2162	1183	1456.48	68	20	293	68	20	293
380	6.33	2175	1191	1463.71	68	20	293	68	20	293
390	6.50	2188	1198	1470.93	68	20	293	68	20	293
400	6.67	2200	1204	1477.59	68	20	293	68	20	293
410	6.83	2212	1211	1484.26	68	20	293	68	20	293
420	7.00	2225	1218	1491.48	68	20	293	68	20	293
430	7.17	2238	1226	1498.71	68	20	293	68	20	293
440	7.33	2250	1232	1505.37	68	20	293	68	20	293
450	7.50	2262	1239	1512.04	68	20	293	68	20	293
460	7.67	2275	1246	1519.26	68	20	293	68	20	293
470	7.83	2288	1253	1526.48	68	20	293	68	20	293
480	8.00	2300	1260	1533.15	68	20	293	68	20	293

Appendix B FDS Scripts

Open Warehouse

```
&HEAD CHID='frame_lab_fire', TITLE='lab_fire'/

&MESH IJK=42,80,16, XB=0,42,0,80,0,16/

&TIME T_END=28800/

&REAC FUEL        = 'POLYURETHANE'
      FYI         = 'C_6.3 H_7.1 O_2.1. NFPA Handbook, Babrauskas'
      SOOT_YIELD = 0.10
      N           = 1.0
      C           = 6.3
      H           = 7.1
      O           = 2.1 /

&MATL ID             = 'STEEL'
      SPECIFIC_HEAT = 0.5
      CONDUCTIVITY  = 50.
      DENSITY        = 7500. /

&SURF ID        = 'STEEL'
      MATL_ID   = 'STEEL'
      THICKNESS = 0.05/

&MULT ID='left', DXB=0.8,0.8,0,0,0.2,0.2, N_LOWER=0, N_UPPER=24/
&MULT ID='right', DXB=-0.8,-0.8,0,0,0.2,0.2, N_LOWER=0, N_UPPER=24/


&OBST XB=1,1.8,0,80,10,10.2, MULT_ID='left', SURF_ID='STEEL', COLOR='RED'/
&OBST XB=40.2,41,0,80,10,10.2, MULT_ID='right', SURF_ID='STEEL',
COLOR='GREEN'/
&OBST XB=1,1,0,80,0,10, SURF_ID='STEEL', COLOR='RED'/
&OBST XB=41,41,0,80,0,10, SURF_ID='STEEL', COLOR='GREEN'/

&VENT MB='XMIN',SURF_ID='OPEN'/
&VENT MB='XMAX',SURF_ID='OPEN'/
&VENT MB='YMIN',SURF_ID='OPEN'/
&VENT MB='YMAX',SURF_ID='OPEN'/
&VENT MB='ZMAX',SURF_ID='OPEN'/


&SURF ID='FIRE', HRRPUA=1, RAMP_Q='ramp 1'/


&VENT XB=11,31,39.5,40.5,0,0, SURF_ID='FIRE'/

&SLCF PBY=40, QUANTITY='TEMPERATURE'/


&DEVC XYZ=17.665,40,13.5, QUANTITY='TEMPERATURE', ID='temp CRI2'/
&DEVC XYZ=1.25,40,9.5, QUANTITY='TEMPERATURE', ID='temp COL'/
&DEVC XYZ=1.5,40,9.75, QUANTITY='TEMPERATURE', ID='temp CRI1'/
&DEVC XYZ=21,40,14.5, QUANTITY='TEMPERATURE', ID='temp APEX'/
&DEVC XYZ=21,40,0.1, QUANTITY='TEMPERATURE', ID='temp FIRE'/

&RAMP ID='ramp 1', T=0, F=0/
&RAMP ID='ramp 1', T=500, F=13000/
&RAMP ID='ramp 1', T=1000, F=34000/
```

Warehouse with Two Openings

```
&HEAD CHID='frame_lab_fire', TITLE='lab_fire'/

&MESH IJK=42,80,16, XB=0,42,0,80,0,16/

&TIME T_END=28800/

&REAC FUEL       = 'POLYURETHANE'
      FYI        = 'C_6.3 H_7.1 O_2.1. NFPA Handbook, Babrauskas'
      SOOT_YIELD = 0.10
      N          = 1.0
      C          = 6.3
      H          = 7.1
      O          = 2.1 /

&MATL ID            = 'STEEL'
      SPECIFIC_HEAT = 0.5
      CONDUCTIVITY  = 50.
      DENSITY       = 7500. /

&SURF ID        = 'STEEL'
      MATL_ID   = 'STEEL'
      THICKNESS = 0.05/

&MULT ID='left', DXB=0.8,0.8,0,0,0.2,0.2, N_LOWER=0, N_UPPER=24/
&MULT ID='right', DXB=-0.8,-0.8,0,0,0.2,0.2, N_LOWER=0, N_UPPER=24/


&OBST XB=1,1.8,0,80,10,10.2, MULT_ID='left', SURF_ID='STEEL', COLOR='RED'/
&OBST XB=40.2,41,0,80,10,10.2, MULT_ID='right', SURF_ID='STEEL',
COLOR='GREEN'/
&OBST XB=1,1,0,80,0,10, SURF_ID='STEEL', COLOR='RED'/
&OBST XB=41,41,0,80,0,10, SURF_ID='STEEL', COLOR='GREEN'/
&HOLE XB=0.75,1.25,70,80,0,5/
&HOLE XB=40.75,41.25,0,10,0,5/

&VENT MB='XMIN',SURF_ID='OPEN'/
&VENT MB='XMAX',SURF_ID='OPEN'/
&VENT MB='ZMAX',SURF_ID='OPEN'/


&SURF ID='FIRE', HRRPUA=1, RAMP_Q='ramp 1'/


&VENT XB=11,31,39.5,40.5,0,0, SURF_ID='FIRE'/

&SLCF PBY=40, QUANTITY='TEMPERATURE'/


&DEVC XYZ=17.665,40,13.5, QUANTITY='TEMPERATURE', ID='temp CRI2'/
&DEVC XYZ=1.25,40,9.5, QUANTITY='TEMPERATURE', ID='temp COL'/
&DEVC XYZ=1.5,40,9.75, QUANTITY='TEMPERATURE', ID='temp CRI1'/
&DEVC XYZ=21,40,14.5, QUANTITY='TEMPERATURE', ID='temp APEX'/
&DEVC XYZ=21,40,0.1, QUANTITY='TEMPERATURE', ID='temp FIRE'/

&RAMP ID='ramp 1', T=0, F=0/
&RAMP ID='ramp 1', T=500, F=13000/
&RAMP ID='ramp 1', T=1000, F=34000/
```

Fully Closed Warehouse

```
&HEAD CHID='frame_lab_fire', TITLE='lab_fire'/

&MESH IJK=42,80,16, XB=0,42,0,80,0,16/

&TIME T_END=28800/

&REAC FUEL        = 'POLYURETHANE'
      FYI         = 'C_6.3 H_7.1 O_2.1. NFPA Handbook, Babrauskas'
      SOOT_YIELD = 0.10
      N           = 1.0
      C           = 6.3
      H           = 7.1
      O           = 2.1 /

&MATL ID             = 'STEEL'
      SPECIFIC_HEAT = 0.5
      CONDUCTIVITY  = 50.
      DENSITY       = 7500. /

&SURF ID        = 'STEEL'
      MATL_ID   = 'STEEL'
      THICKNESS = 0.05/

&MULT ID='left', DXB=0.8,0.8,0,0,0.2,0.2, N_LOWER=0, N_UPPER=24/
&MULT ID='right', DXB=-0.8,-0.8,0,0,0.2,0.2, N_LOWER=0, N_UPPER=24/


&OBST XB=1,1.8,0,80,10,10.2, MULT_ID='left', SURF_ID='STEEL', COLOR='RED'/
&OBST XB=40.2,41,0,80,10,10.2, MULT_ID='right', SURF_ID='STEEL',
COLOR='GREEN'/
&OBST XB=1,1,0,80,0,10, SURF_ID='STEEL', COLOR='RED'/
&OBST XB=41,41,0,80,0,10, SURF_ID='STEEL', COLOR='GREEN'/


&VENT MB='XMIN',SURF_ID='OPEN'/
&VENT MB='XMAX',SURF_ID='OPEN'/
&VENT MB='ZMAX',SURF_ID='OPEN'/


&SURF ID='FIRE', HRRPUA=500/


&VENT XB=11,31,39.5,40.5,0,0, SURF_ID='FIRE'/

&SLCF PBY=40, QUANTITY='TEMPERATURE'/


&DEVC XYZ=17.665,40,13.5, QUANTITY='TEMPERATURE', ID='temp CRI2'/
&DEVC XYZ=1.25,40,9.5, QUANTITY='TEMPERATURE', ID='temp COL'/
&DEVC XYZ=1.5,40,9.75, QUANTITY='TEMPERATURE', ID='temp CRI1'/
&DEVC XYZ=21,40,14.5, QUANTITY='TEMPERATURE', ID='temp APEX'/
&DEVC XYZ=21,40,0.1, QUANTITY='TEMPERATURE', ID='temp FIRE'/
```

Appendix C Selected data gathered from FDS

Opened Warehouse						
Time		**Temperature C**				
(s)	**(hr)**	Fire	Apex	Max Positive Moment	Fixed Connection Beam	Fixed Connection Column
0.00	**0.00**	20.00	20.00	20.00	20.00	20.00
144.06	**0.04**	648.10	156.11	157.16	23.00	23.00
288.02	**0.08**	808.20	253.45	285.53	34.95	34.95
432.04	**0.12**	809.45	417.46	435.40	27.22	27.22
576.02	**0.16**	813.66	454.14	485.31	165.13	165.13
720.01	**0.20**	840.29	777.61	662.23	124.10	124.10
864.01	**0.24**	811.22	813.05	862.96	146.38	146.38
1008.03	**0.28**	876.20	954.36	902.97	176.23	176.23
1152.02	**0.32**	834.74	875.89	756.12	316.18	316.18
1296.00	**0.36**	881.25	980.90	778.29	311.69	311.69
1440.02	**0.40**	855.87	954.80	777.34	341.45	341.45
1584.01	**0.44**	869.95	912.32	798.50	266.26	266.26
1728.03	**0.48**	863.01	888.96	851.87	190.55	190.55
1872.00	**0.52**	850.27	945.68	881.56	342.01	342.01
2016.04	**0.56**	796.75	896.32	864.84	333.30	333.30
2160.01	**0.60**	870.83	954.33	770.93	313.90	313.90
2304.02	**0.64**	841.22	965.77	1050.49	264.70	264.70
2448.01	**0.68**	839.35	823.34	932.99	399.62	399.62
2592.02	**0.72**	861.94	966.36	887.11	386.48	386.48
2736.00	**0.76**	903.10	1000.10	1032.79	346.97	346.97
2880.00	**0.80**	817.59	898.20	810.37	388.85	388.85
3024.02	**0.84**	838.25	813.99	783.97	341.97	341.97
3168.01	**0.88**	830.43	831.35	915.02	342.88	342.88
3312.02	**0.92**	861.03	923.95	870.34	238.29	238.29
3456.04	**0.96**	843.43	843.93	909.84	430.16	430.16
3600.01	**1.00**	824.85	840.41	877.49	375.19	375.19
3744.01	**1.04**	836.33	899.98	900.70	344.48	344.48
3888.01	**1.08**	809.45	865.54	814.89	417.76	417.76
4032.01	**1.12**	863.12	844.94	806.61	365.35	365.35
4176.01	**1.16**	827.44	914.60	1004.70	340.08	340.08
4320.02	**1.20**	862.61	945.71	907.15	223.36	223.36
4464.03	**1.24**	808.90	905.61	831.83	380.00	380.00
4608.04	**1.28**	838.47	931.81	930.32	325.32	325.32
4752.00	**1.32**	861.67	899.84	905.80	317.05	317.05
4896.02	**1.36**	799.70	857.66	802.55	399.44	399.44
5040.01	**1.40**	862.20	958.39	921.29	384.58	384.58
5184.03	**1.44**	859.35	938.97	905.38	305.41	305.41
5328.02	**1.48**	819.03	881.43	801.28	400.98	400.98
5472.01	**1.52**	864.00	880.12	880.76	378.82	378.82
5616.02	**1.56**	792.34	926.98	958.30	351.15	351.15
5760.02	**1.60**	813.19	864.29	967.42	388.88	388.88
5904.01	**1.64**	818.73	775.26	791.05	407.21	407.21
6048.03	**1.68**	838.84	822.60	818.74	398.56	398.56

6192.01	**1.72**	853.07	930.69	818.46	358.76	358.76
6336.03	**1.76**	859.00	936.36	816.64	248.97	248.97
6480.01	**1.80**	827.67	853.21	905.01	366.47	366.47
6624.03	**1.84**	820.18	902.50	894.01	338.45	338.45
6768.01	**1.88**	846.99	824.33	892.14	309.57	309.57
6912.02	**1.92**	900.59	1000.76	920.12	381.12	381.12
7056.02	**1.96**	837.37	995.79	957.86	305.39	305.39
7200.01	**2.00**	819.91	821.88	909.88	376.69	376.69
7344.02	**2.04**	858.90	916.45	874.52	401.09	401.09
7488.01	**2.08**	844.71	890.33	936.54	319.26	319.26
7632.03	**2.12**	797.74	911.53	1018.85	315.88	315.88
7776.02	**2.16**	830.40	820.77	895.52	375.51	375.51
7920.03	**2.20**	843.99	814.27	845.42	428.28	428.28
8064.01	**2.24**	821.16	831.27	898.80	424.67	424.67
8208.02	**2.28**	845.68	848.28	900.07	319.15	319.15
8352.02	**2.32**	865.02	1072.84	1013.72	383.63	383.63
8496.03	**2.36**	833.58	852.43	821.13	406.79	406.79
8640.03	**2.40**	820.36	825.58	796.63	398.89	398.89
8784.04	**2.44**	809.90	805.99	868.37	402.49	402.49
8928.03	**2.48**	877.06	954.59	847.48	447.60	447.60
9072.03	**2.52**	881.52	1007.38	971.40	374.64	374.64
9216.02	**2.56**	829.57	905.54	842.19	323.64	323.64
9360.03	**2.60**	860.43	927.42	953.80	395.50	395.50
9504.01	**2.64**	876.38	949.39	947.89	315.39	315.39
9648.00	**2.68**	788.51	901.25	877.17	342.06	342.06
9792.00	**2.72**	808.20	878.16	909.97	444.35	444.35
9936.01	**2.76**	833.94	875.73	955.21	344.48	344.48
10080.00	**2.80**	828.91	879.96	833.98	376.26	376.26
10224.04	**2.84**	843.36	814.76	822.43	347.65	347.65
10368.00	**2.88**	861.98	877.33	703.21	422.46	422.46
10512.01	**2.92**	860.72	958.38	916.74	445.00	445.00
10656.02	**2.96**	814.31	886.74	899.36	372.01	372.01
10800.03	**3.00**	855.60	965.64	940.59	374.18	374.18
10944.03	**3.04**	817.88	863.12	873.48	342.63	342.63
11088.00	**3.08**	844.20	785.27	851.21	363.37	363.37
11232.02	**3.12**	877.69	940.17	970.79	429.89	429.89
11376.00	**3.16**	869.02	946.43	997.58	419.25	419.25
11520.01	**3.20**	833.33	895.32	953.27	331.90	331.90
11664.02	**3.24**	895.59	1025.63	1001.40	372.45	372.45
11808.01	**3.28**	862.85	972.74	1006.21	313.74	313.74
11952.02	**3.32**	802.14	834.92	890.54	369.98	369.98
12096.03	**3.36**	817.63	838.79	824.01	416.77	416.77
12240.03	**3.40**	851.07	910.91	936.84	412.58	412.58
12384.02	**3.44**	871.41	1021.48	928.79	268.69	268.69
12528.01	**3.48**	827.46	908.13	823.21	295.63	295.63
12672.03	**3.52**	861.67	901.59	819.78	452.49	452.49
12816.03	**3.56**	867.35	901.53	979.26	422.95	422.95
12960.01	**3.60**	830.15	1015.05	900.76	399.89	399.89
13104.01	**3.64**	816.58	851.62	845.72	329.77	329.77
13248.03	**3.68**	840.71	905.55	869.23	348.95	348.95
13392.03	**3.72**	787.51	951.50	998.13	368.75	368.75

13536.01	**3.76**	857.19	961.97	954.34	330.18	330.18
13680.03	**3.80**	846.52	876.09	848.59	336.42	336.42
13824.03	**3.84**	803.47	808.55	837.66	358.83	358.83
13968.00	**3.88**	824.14	829.95	903.06	365.98	365.98
14112.03	**3.92**	860.27	843.60	962.42	389.35	389.35
14256.01	**3.96**	817.03	747.94	784.35	356.38	356.38
14400.02	**4.00**	830.50	862.22	990.67	366.35	366.35

2-Door Opened Warehouse

Time		**Temperature C**				
(s)	**(hr)**	Fire	Apex	Max Positive Moment	Fixed Connection Beam	Fixed Connection Column
0	**0**	20	20	20	20	20
144.04	**0.04**	699.67	228.21	232.74	91.17	91.17
288.02	**0.08**	932.94	575.67	557.54	275.52	275.52
432.05	**0.12**	870.41	791.56	919.11	343.39	343.39
576.03	**0.16**	752.91	731.15	788.01	475.57	475.57
720.01	**0.20**	248.89	461.73	478.22	344.84	344.84
864.01	**0.24**	191.59	420.92	429.88	332.87	332.87
1008.02	**0.28**	160.89	437.48	426.81	313.45	313.45
1152.04	**0.32**	161.43	452.08	459.15	344.39	344.39
1296.02	**0.36**	173.69	429.53	427.22	319.34	319.34
1440.03	**0.40**	166.52	412.25	423.46	327.22	327.22
1584.02	**0.44**	166.67	431.27	435.23	357.70	357.70
1728.01	**0.48**	166.98	436.43	438.83	339.30	339.30
1872.01	**0.52**	171.40	417.73	424.59	352.29	352.29
2016.01	**0.56**	166.36	424.55	436.02	341.01	341.01
2160.02	**0.60**	167.30	434.79	444.03	355.88	355.88
2304.02	**0.64**	166.47	427.74	445.82	342.98	342.98
2448.02	**0.68**	167.17	442.18	446.27	362.91	362.91
2592.02	**0.72**	178.10	439.32	434.45	356.07	356.07
2736.03	**0.76**	167.76	443.63	446.78	337.84	337.84
2880.04	**0.80**	167.92	443.94	453.78	362.59	362.59
3024.04	**0.84**	177.88	444.61	459.56	360.41	360.41
3168.03	**0.88**	179.25	444.69	453.09	362.58	362.58
3312.03	**0.92**	179.24	443.05	448.92	349.80	349.80
3456.02	**0.96**	172.70	433.62	455.43	352.77	352.77
3600.03	**1.00**	175.12	465.25	470.72	366.15	366.15
3744.04	**1.04**	172.36	442.01	453.02	361.84	361.84
3888.01	**1.08**	172.54	428.05	443.06	349.68	349.68
4032.02	**1.12**	172.28	436.78	435.02	348.88	348.88
4176.03	**1.16**	178.40	423.09	441.45	351.19	351.19
4320.04	**1.20**	178.23	447.44	454.99	369.40	369.40
4464.04	**1.24**	182.57	466.03	484.54	373.76	373.76
4608.04	**1.28**	186.46	470.53	495.71	395.33	395.33
4752.01	**1.32**	174.49	450.12	465.44	375.43	375.43
4896.00	**1.36**	176.17	439.97	454.84	371.12	371.12
5040.02	**1.40**	183.52	447.42	445.99	356.88	356.88

5184.02	**1.44**	176.20	444.70	447.16	358.73	358.73
5328.00	**1.48**	170.41	428.87	430.00	345.13	345.13
5472.00	**1.52**	172.77	439.38	448.05	359.39	359.39
5616.03	**1.56**	175.60	462.91	466.70	377.24	377.24
5760.01	**1.60**	191.59	493.77	492.51	394.05	394.05
5904.01	**1.64**	182.40	473.54	469.11	380.65	380.65
6048.03	**1.68**	182.28	479.52	476.58	367.07	367.07
6192.02	**1.72**	177.65	454.15	457.47	370.21	370.21
6336.01	**1.76**	176.39	439.24	454.00	375.39	375.39
6480.02	**1.80**	174.17	413.42	416.70	360.53	360.53
6624.02	**1.84**	174.47	411.09	415.04	353.59	353.59
6768.02	**1.88**	173.47	428.09	431.58	367.55	367.55
6912.04	**1.92**	186.76	446.54	457.37	383.50	383.50
7056.01	**1.96**	182.29	452.67	466.43	400.86	400.86
7200.01	**2.00**	193.60	466.50	479.30	398.77	398.77
7344.02	**2.04**	181.74	412.86	424.22	352.31	352.31
7488.00	**2.08**	174.51	432.36	436.96	376.25	376.25
7632.04	**2.12**	173.96	417.43	428.31	360.21	360.21
7776.03	**2.16**	178.40	454.80	459.75	374.52	374.52
7920.03	**2.20**	181.31	433.67	437.97	364.15	364.15
8064.03	**2.24**	175.19	436.83	443.06	367.20	367.20
8208.00	**2.28**	177.95	454.23	457.15	387.06	387.06
8352.03	**2.32**	177.43	447.35	457.09	375.68	375.68
8496.00	**2.36**	182.99	466.80	469.59	389.05	389.05
8640.01	**2.40**	183.82	447.12	449.98	373.34	373.34
8784.04	**2.44**	189.41	469.64	481.47	385.69	385.69
8928.01	**2.48**	183.89	445.17	455.78	390.41	390.41
9072.02	**2.52**	178.22	436.56	448.25	375.36	375.36
9216.02	**2.56**	181.91	418.09	427.84	374.23	374.23
9360.00	**2.60**	189.21	467.49	483.03	398.04	398.04
9504.01	**2.64**	180.30	450.78	461.28	381.27	381.27
9648.02	**2.68**	185.91	451.81	471.59	382.15	382.15
9792.02	**2.72**	181.61	428.99	440.98	376.99	376.99
9936.03	**2.76**	179.72	430.37	437.60	353.87	353.87
10080.01	**2.80**	181.42	433.19	442.50	376.25	376.25
10224.03	**2.84**	178.80	424.56	431.48	353.54	353.54
10368.02	**2.88**	183.28	449.90	457.04	369.55	369.55
10512.04	**2.92**	183.14	462.07	468.11	388.59	388.59
10656.04	**2.96**	187.07	492.65	488.42	390.91	390.91
10800.01	**3.00**	189.10	447.26	449.40	380.21	380.21
10944.01	**3.04**	182.07	445.16	447.98	379.20	379.20
11088.01	**3.08**	177.43	452.91	457.44	374.53	374.53
11232.01	**3.12**	178.62	422.72	427.50	364.97	364.97
11376.04	**3.16**	188.21	455.25	467.52	386.97	386.97
11520.01	**3.20**	187.20	463.88	479.15	403.51	403.51
11664.00	**3.24**	188.35	448.59	462.71	392.23	392.23
11808.02	**3.28**	183.26	466.92	482.76	402.78	402.78
11952.01	**3.32**	181.17	448.05	455.88	377.28	377.28
12096.02	**3.36**	178.65	435.00	443.08	380.77	380.77
12240.01	**3.40**	181.44	440.43	447.38	376.14	376.14
12384.02	**3.44**	184.36	436.15	438.57	384.04	384.04

12528.01	**3.48**	179.41	447.66	444.41	376.57	376.57
12672.03	**3.52**	184.00	436.62	438.63	379.21	379.21
12816.03	**3.56**	181.17	446.91	446.76	382.52	382.52
12960.01	**3.60**	179.36	467.46	480.15	398.88	398.88
13104.01	**3.64**	184.08	457.96	459.05	403.26	403.26
13248.02	**3.68**	182.71	457.02	461.73	388.94	388.94
13392.01	**3.72**	181.24	451.61	461.89	387.76	387.76
13536.00	**3.76**	184.67	448.95	449.79	375.90	375.90
13680.03	**3.80**	184.71	458.77	470.76	401.98	401.98
13824.02	**3.84**	193.92	442.19	458.26	390.49	390.49
13968.02	**3.88**	179.13	451.87	463.00	395.01	395.01
14112.02	**3.92**	189.05	448.61	466.44	384.60	384.60
14256.03	**3.96**	180.46	455.73	467.22	390.93	390.93
14400.04	**4.00**	183.40	458.21	474.11	391.74	391.74

Closed Warehouse

Time		**Temperature C**				
s	**hr**	Fire	Apex	Max Positive Moment	Fixed Connection Beam	Fixed Connection Column
0.00	**0.00**	20.00	20.00	20.00	20.00	20.00
144.08	**0.04**	325.17	108.02	105.61	57.51	57.51
288.03	**0.08**	317.60	126.74	116.87	93.75	93.75
432.00	**0.12**	342.68	118.24	123.41	155.44	155.44
576.03	**0.16**	266.59	134.91	139.46	119.86	119.86
720.05	**0.20**	303.73	150.61	155.19	133.38	133.38
864.04	**0.24**	256.50	136.23	139.10	136.45	136.45
1008.03	**0.28**	263.86	141.97	143.89	125.39	125.39
1152.00	**0.32**	369.05	137.14	134.70	123.56	123.56
1296.02	**0.36**	336.00	142.36	142.75	121.93	121.93
1440.01	**0.40**	274.23	153.04	153.38	128.88	128.88
1584.02	**0.44**	351.84	142.83	138.61	124.52	124.52
1728.02	**0.48**	352.66	160.22	159.57	131.32	131.32
1872.02	**0.52**	285.73	142.29	143.38	124.73	124.73
2016.01	**0.56**	265.33	147.49	147.86	133.38	133.38
2160.02	**0.60**	305.80	143.53	142.99	133.20	133.20
2304.06	**0.64**	215.05	150.63	149.64	161.08	161.08
2448.05	**0.68**	113.80	134.57	138.05	128.43	128.43
2592.04	**0.72**	91.98	134.25	141.56	133.30	133.30
2736.07	**0.76**	76.07	153.44	148.58	134.43	134.43
2880.02	**0.80**	78.05	144.18	142.58	112.23	112.23
3024.05	**0.84**	70.38	158.80	159.40	124.76	124.76
3168.04	**0.88**	71.27	113.65	113.20	141.58	141.58
3312.05	**0.92**	60.38	125.65	127.11	107.61	107.61
3456.09	**0.96**	66.08	131.25	127.44	97.63	97.63
3600.06	**1.00**	60.06	128.16	127.74	101.90	101.90
3744.12	**1.04**	64.65	109.35	108.74	106.34	106.34
3888.11	**1.08**	52.14	111.13	110.16	91.84	91.84
4032.03	**1.12**	51.58	104.82	102.78	88.82	88.82

4176.02	**1.16**	49.77	94.26	93.98	78.32	78.32
4320.09	**1.20**	45.38	79.53	80.20	71.23	71.23
4464.10	**1.24**	47.60	71.50	71.89	63.31	63.31
4608.17	**1.28**	46.59	72.00	72.12	61.61	61.61
4752.18	**1.32**	47.34	68.75	69.20	58.46	58.46
4896.13	**1.36**	43.62	79.70	76.93	55.22	55.22
5040.03	**1.40**	39.86	104.35	76.67	53.32	53.32
5184.01	**1.44**	42.88	65.87	66.36	53.49	53.49
5328.16	**1.48**	41.21	64.14	64.87	55.00	55.00
5472.12	**1.52**	37.56	62.30	62.66	53.13	53.13
5616.10	**1.56**	32.75	60.09	60.64	51.15	51.15
5760.01	**1.60**	31.37	59.86	59.21	51.18	51.18
5904.14	**1.64**	34.46	59.54	59.62	51.76	51.76
6048.01	**1.68**	35.09	62.75	61.30	49.62	49.62
6192.00	**1.72**	35.19	58.99	59.19	59.16	59.16
6336.01	**1.76**	35.80	57.95	57.46	54.54	54.54
6480.04	**1.80**	35.32	58.21	58.18	53.00	53.00
6624.05	**1.84**	34.05	60.73	59.42	50.66	50.66
6768.15	**1.88**	32.86	69.16	78.39	50.30	50.30
6912.08	**1.92**	31.12	71.65	78.46	49.50	49.50
7056.05	**1.96**	31.36	71.47	67.92	48.26	48.26
7200.03	**2.00**	31.84	65.18	61.16	48.39	48.39
7344.14	**2.04**	31.69	71.67	74.11	47.51	47.51
7488.02	**2.08**	32.13	70.31	78.36	47.45	47.45
7632.10	**2.12**	31.34	62.19	59.37	47.24	47.24
7776.12	**2.16**	30.87	67.95	72.20	46.89	46.89
7920.05	**2.20**	31.52	68.31	65.28	46.49	46.49
8064.06	**2.24**	30.46	73.63	59.22	45.97	45.97
8208.06	**2.28**	30.15	83.08	66.59	46.62	46.62
8352.04	**2.32**	32.24	69.73	63.48	45.43	45.43
8496.05	**2.36**	33.64	81.54	60.96	45.48	45.48
8640.17	**2.40**	32.42	81.71	61.90	45.33	45.33
8784.02	**2.44**	32.04	91.35	67.05	45.85	45.85
8928.02	**2.48**	30.74	76.57	63.37	45.24	45.24
9072.02	**2.52**	29.39	72.65	62.52	44.35	44.35
9216.00	**2.56**	30.69	71.53	58.73	44.58	44.58
9360.12	**2.60**	30.61	66.74	57.87	44.12	44.12
9504.01	**2.64**	29.59	73.40	61.41	43.55	43.55
9648.10	**2.68**	30.28	76.29	59.63	44.32	44.32
9792.00	**2.72**	28.97	59.11	55.67	43.58	43.58
9936.07	**2.76**	30.39	68.86	58.59	43.76	43.76
10080.07	**2.80**	29.71	81.28	60.69	44.06	44.06
10224.09	**2.84**	30.04	68.24	58.43	43.26	43.26
10368.06	**2.88**	29.68	78.68	57.22	43.48	43.48
10512.04	**2.92**	28.83	75.29	60.27	43.64	43.64
10656.06	**2.96**	29.32	64.54	58.45	43.65	43.65
10800.05	**3.00**	28.98	68.35	58.67	42.83	42.83
10944.06	**3.04**	28.75	74.98	60.02	42.77	42.77
11088.00	**3.08**	28.81	69.08	57.95	42.69	42.69
11232.07	**3.12**	29.35	67.60	56.44	43.58	43.58
11376.11	**3.16**	29.24	70.83	58.54	42.34	42.34

11520.08	**3.20**	29.08	70.89	59.23	42.66	42.66
11664.15	**3.24**	27.43	69.17	59.01	42.26	42.26
11808.04	**3.28**	27.37	74.74	57.73	42.45	42.45
11952.12	**3.32**	28.09	85.55	63.27	42.50	42.50
12096.05	**3.36**	28.32	67.85	57.22	41.89	41.89
12240.05	**3.40**	28.30	70.55	59.65	42.54	42.54
12384.08	**3.44**	29.25	68.36	56.55	41.32	41.32
12528.13	**3.48**	27.78	71.03	58.44	40.97	40.97
12672.02	**3.52**	28.43	65.63	55.29	42.27	42.27
12816.02	**3.56**	28.40	67.41	57.96	41.84	41.84
12960.03	**3.60**	27.98	66.59	57.53	41.40	41.40
13104.08	**3.64**	29.06	68.90	56.56	41.27	41.27
13248.01	**3.68**	28.65	60.98	55.39	42.12	42.12
13392.05	**3.72**	27.66	69.62	57.57	41.64	41.64
13536.02	**3.76**	26.38	67.88	55.46	41.40	41.40
13680.08	**3.80**	27.74	64.72	54.59	41.09	41.09
13824.03	**3.84**	27.09	66.99	55.71	41.11	41.11
13968.03	**3.88**	26.70	66.90	54.14	41.33	41.33
14112.02	**3.92**	27.17	62.55	55.93	41.04	41.04
14256.06	**3.96**	28.09	60.30	53.00	40.51	40.51
14400.07	**4.00**	26.74	65.48	54.14	40.25	40.25

Appendix D Detail Loads Calculations

Dead & Live Load

Roofing Dead Load						
Water Proofing	0.03	kN/m^2	0.09	kN/m	T C3-1	Single-Ply Sheet
Insulation	0.04		0.12			Rigid Insulation
Metal Decking	0.14		0.42			18 gage
Total	0.21		0.63			

Live Load					
Live Load	0.96	kN/m^2	2.88	kN/m	T 4-1

Snow Loads

Flat Roof Snow Load			
C_e	0.9		T 7-2
C_t	1		T 7-3
I_s	1.2		T 1.5-2
P_g	39	psf	T C7-1
	1.87	kN/m^2	
P_m	2.24	kN/m^2	S 7.3.4
P_f	1.41	kN/m^2	EQ 7.3-1
	2.24		

Slopped Roof Snow Load			
C_s	0.8		F 7-2a
P_s	1.79	kN/m^2	E 7.4-1

Unbalanced Snow Load						
Need To Be Checked						
h_d	0.91	m				F 7-9
γ	3.00	kN/m^2				EQ 7.7-1
S	4	m			Slope	
Rec. Surcharge	1.37	kN/m^2			Leeward	S 7.6.1
Extension	4.88	m				S 7.6.1
P_s **on Windward**	0.54	kN/m^2	1.61	kN/m		S 7.6.1
P_s **on Leeward**	3.16	kN/m^2	9.49	kN/m	4.877	S 7.6.1
	1.79	kN/m^2	5.38	kN/m	15.123	

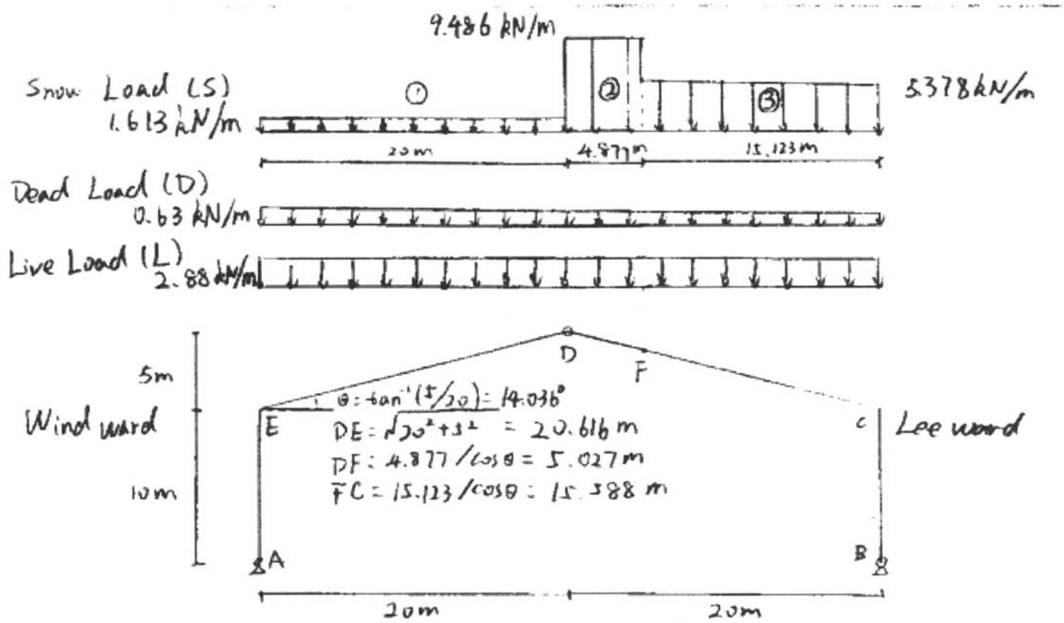
Wind Loads

Wind Speed and Factors			
Speed, V	63	m/s	F 26.5-1
K_d	0.85		T 26.6-1
K_{zt}	1		S 26.8-1
K_h/K_z	0.7		T 28.3-1
q_h/q_z	1.448	kN/m2	EQ 28.3-1
GC_{pi}	0.18		T 26.11-1
	-0.18		

Loading Condition A (T 28.4-1)							
Section	**GC_{pf}**			**Design Load**		**Design Pressure**	**Design Load**
	5	20	14.036	**With $+GC_{pi}$**	**With $-GC_{pi}$**		
1	0.4	0.53	0.478	0.432	0.953	0.953	2.859
2	-0.69	-0.69	-0.690	-1.259	-0.738	-1.259	-3.778
3	-0.37	-0.48	-0.436	-0.892	-0.371	-0.892	-2.676
4	-0.29	-0.43	-0.374	-0.802	-0.281	-0.802	-2.407
1E	0.61	0.8	0.724	0.788	1.309	1.309	3.928
2E	-1.07	-1.07	-1.070	-1.810	-1.288	-1.810	-5.429
3E	-0.53	-0.69	-0.626	-1.167	-0.646	-1.167	-3.502
4E	-0.43	-0.64	-0.557	-1.066	-0.545	-1.066	-3.199

Loading Condition B (T 28.4-1)					
Section	**GC_{pf}**	**Design Load**		**Design Pressure**	**Design Load**
		With $+GC_{pi}$	**With $-GC_{pi}$**		
1	-0.45	-0.912	-0.391	-0.912	-2.7360268
2	-0.69	-1.259	-0.738	-1.259	-3.7783227
3	-0.37	-0.796	-0.275	-0.796	-2.3885948
4	-0.45	-0.912	-0.391	-0.912	-2.7360268
5	0.4	0.318	0.840	0.840	2.51888179
6	-0.29	-0.680	-0.159	-0.680	-2.0411628
1E	-0.48	-0.955	-0.434	-0.955	-2.8663138
2E	-1.07	-1.810	-1.288	-1.810	-5.4286246
3E	-0.53	-1.028	-0.507	-1.028	-3.0834587
4E	-0.48	-0.955	-0.434	-0.955	-2.8663138
5E	0.61	0.622	1.144	1.144	3.43089072
6E	-0.43	-0.883	-0.362	-0.883	-2.6491688

Appendix E Frame Analysis – Hand Calculations



• Load Combination:

$1.2D + 1.6S + L$

Section ①

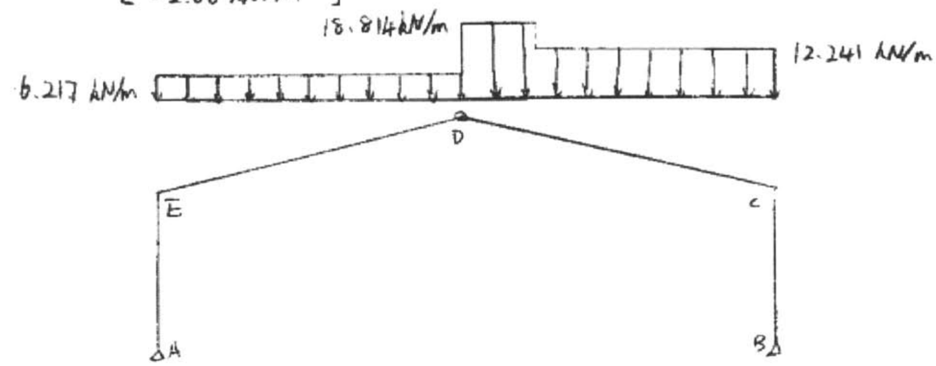
$D = 0.63$ kN/m
$S = 1.613$ kN/m
$L = 2.88$ kN/m
→ $1.2D + 1.6S + L = 6.217$ kN/m

Section ②

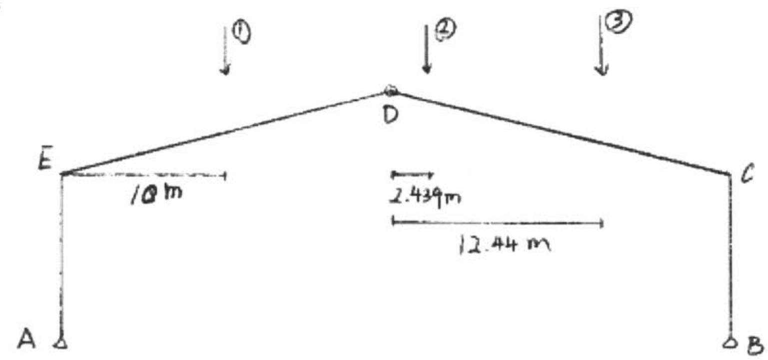
$D = 0.63$ kN/m
$S = 9.486$ kN/m
$L = 2.88$ kN/m
→ $1.2D + 1.6S + L = 18.814$ kN/m

Section ③

$D = 0.63$ kN/m
$S = 5.378$ kN/m
$L = 2.88$ kN/m
→ $1.2D + 1.6S + L = 12.241$ kN/m



Lump Loads



①. 6.217 kN/m × 20 m = 124.34 kN
②. 18.814 kN/m × 4.877 m = 91.756 kN
③. 12.241 kN/m × 15.123 m = 185.121 kN

Reaction Force at Supports

Sum the Moment about A. Moment Equilibrium

$$\Sigma M_A = 0$$
$$\Sigma M_A = 124.34\,kN \times 10\,m + 91.756\,kN \times 22.439\,m + 185.121\,kN \times 32.44\,m - V_B \times 40\,m = 0$$
$$\uparrow V_B = 232.691\,kN$$

Force Equlibrium

$$V_A + V_B = ① + ② + ③$$
$$\Downarrow$$
$$V_A + 232.691\,kN = 124.34\,kN + 91.756\,kN + 185.121\,kN$$
$$\Downarrow$$
$$\uparrow V_A = 168.526\,kN$$

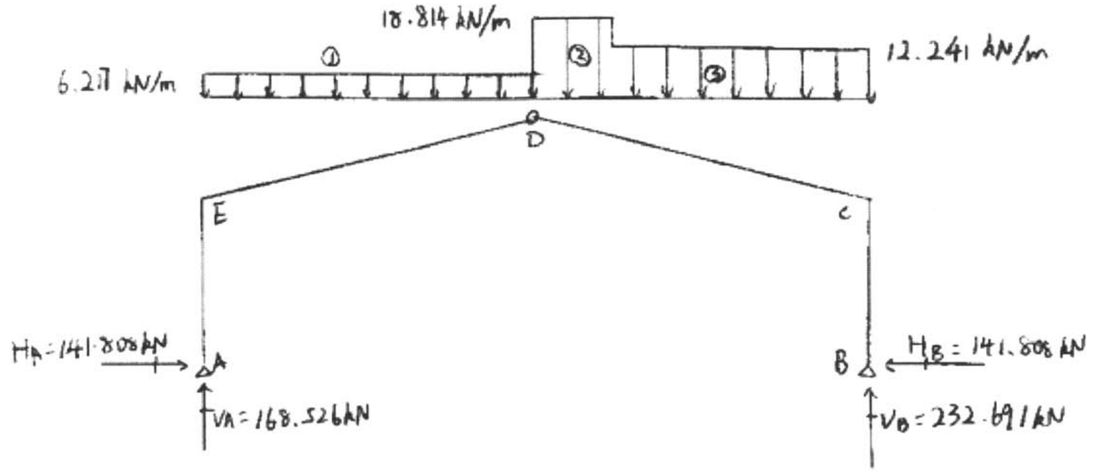
Horizontal Reactions

Sum the Moment at D for Section AED of the Frame

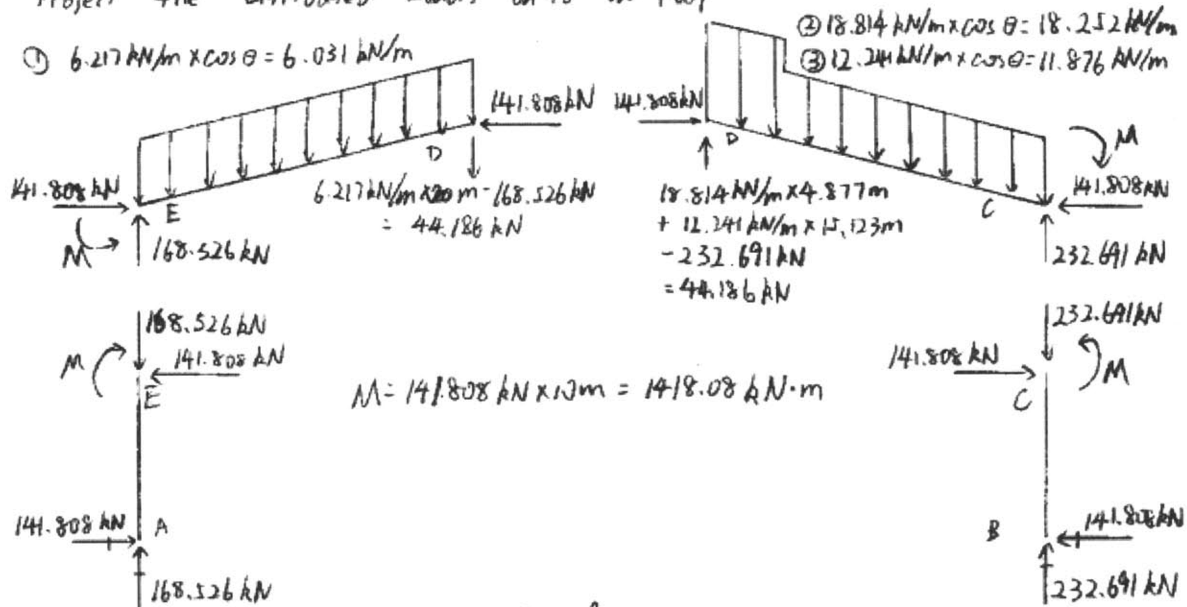
$$\Sigma M_D = 0$$
$$\Sigma M_D = V_A \times 20\,m - 124.34\,kN \times 10\,m - H_A \times 15\,m = 0$$
$$\Downarrow$$
$$\rightarrow H_A = 141.808\,kN$$

Force Equilibrium

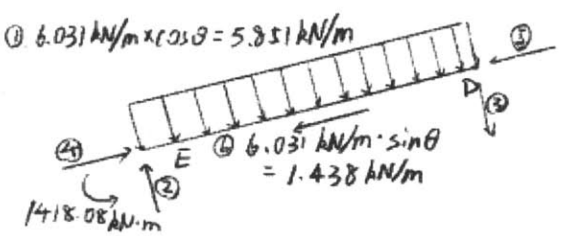
$$H_A + H_B = 0$$
$$\Downarrow$$
$$\leftarrow H_B = 141.808\,kN$$



Project the Distributed Loads on to the Roof



End forces



$\Sigma M_D = 0$

$\Sigma M_D = 5.851\ kN/m \times 20.616^2\ m\ /2 + 1418.08\ kN \cdot m$
$- ② \cdot 20.616\ m = 0$

②: 129.098 kN

③: 5.851 kN/m × 20.616 m − 129.098 kN
8.474 kN

④: 168.526 kN × sin θ + 141.808 kN × cos θ
= 178.447 kN

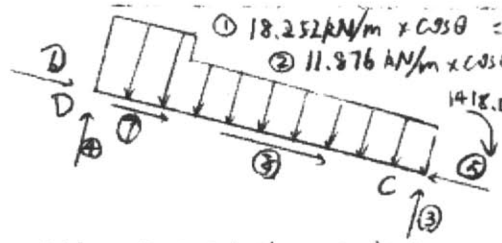
⑤: 1.438 kN/m × 20.616 m − 178.447 kN
= 148.802 kN

① $18.252\,kN/m \times \cos\theta = 17.707\,kN/m$

② $11.876\,kN/m \times \cos\theta = 11.521\,kN/m$

⑦ $18.252\,kN/m \times \sin\theta = 4.427\,kN/m$

⑧ $11.876\,kN/m \times \sin\theta = 2.880\,kN/m$



$\Sigma M_D = 0$

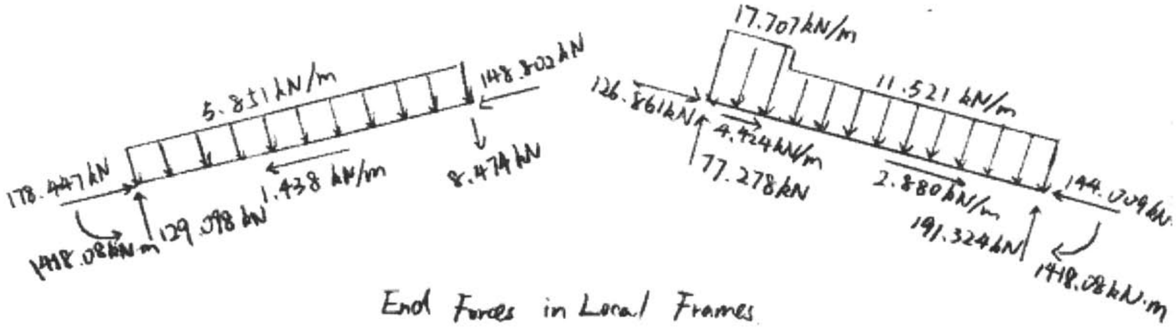
$\Sigma M_D = 17.707\,kN/m \times 5.027\,m/2 + 11.521\,kN/m \times 15.588\,m \times (15.588\,m/2 + 5.027\,m) + 1418.08\,kN\cdot m - ③ \cdot 20.616\,m$

③: $191.324\,kN$

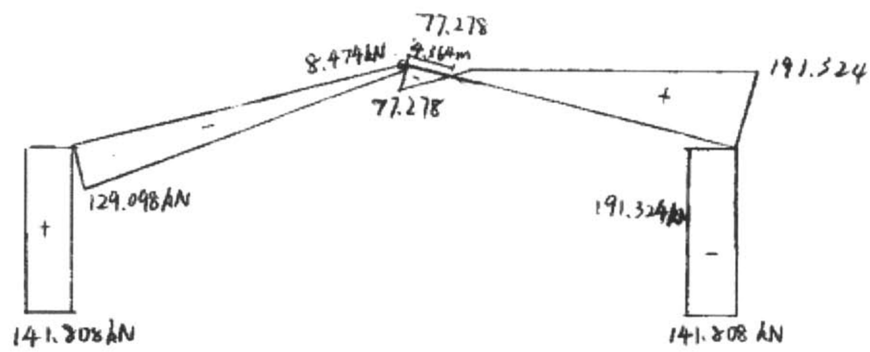
④: $17.707\,kN/m \times 5.027\,m + 11.321\,kN/m \times 15.588\,m - 191.324\,kN = 77.278\,kN$

⑤: $232.691\,kN \times \sin\theta + 141.808 \times \cos\theta = 194.009\,kN$

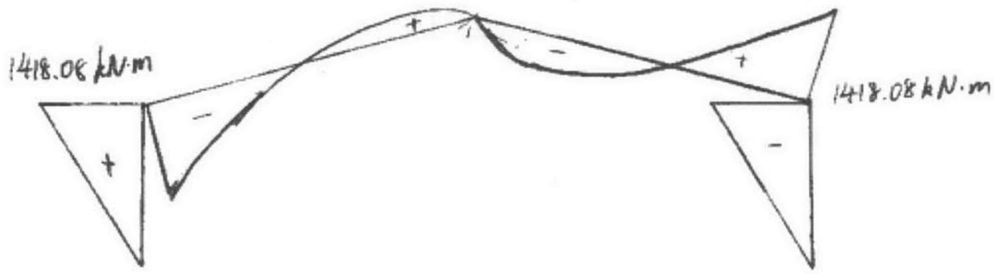
⑥: $4.427\,kN/m \times 5.027\,m + 2.880\,kN/m \times 15.588\,m - 194.009\,kN = 126.861\,kN$



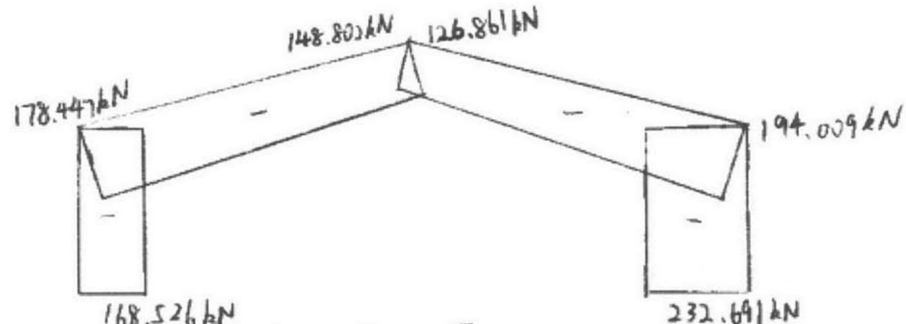
End Forces in Local Frames



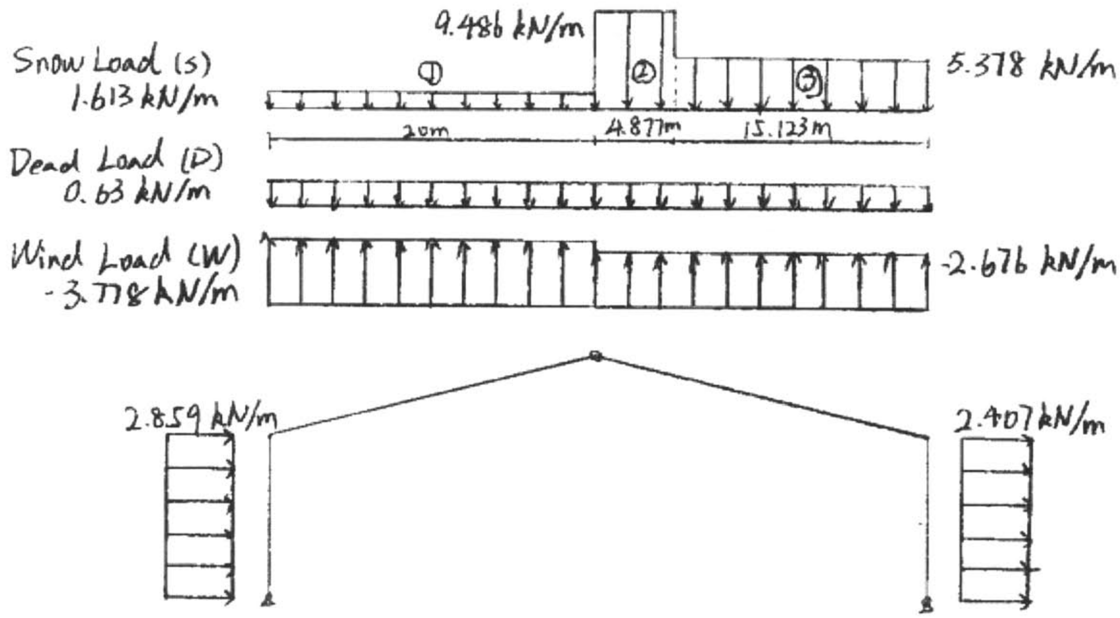
Shear V



Moment, M



Axial Force: F



Load combination for roof

$1.2D + 1.6S + 0.5W$

Section ①

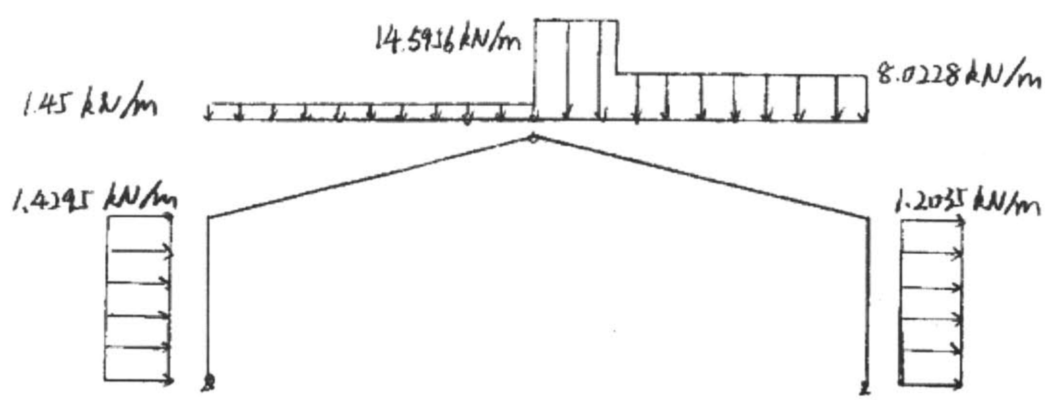
$D = 0.63$ kN/m
$S = 1.613$ kN/m
$W = -3.778$ kN/m
$\rightarrow 1.2D + 1.6S + 0.5W = 1.45$ kN/m

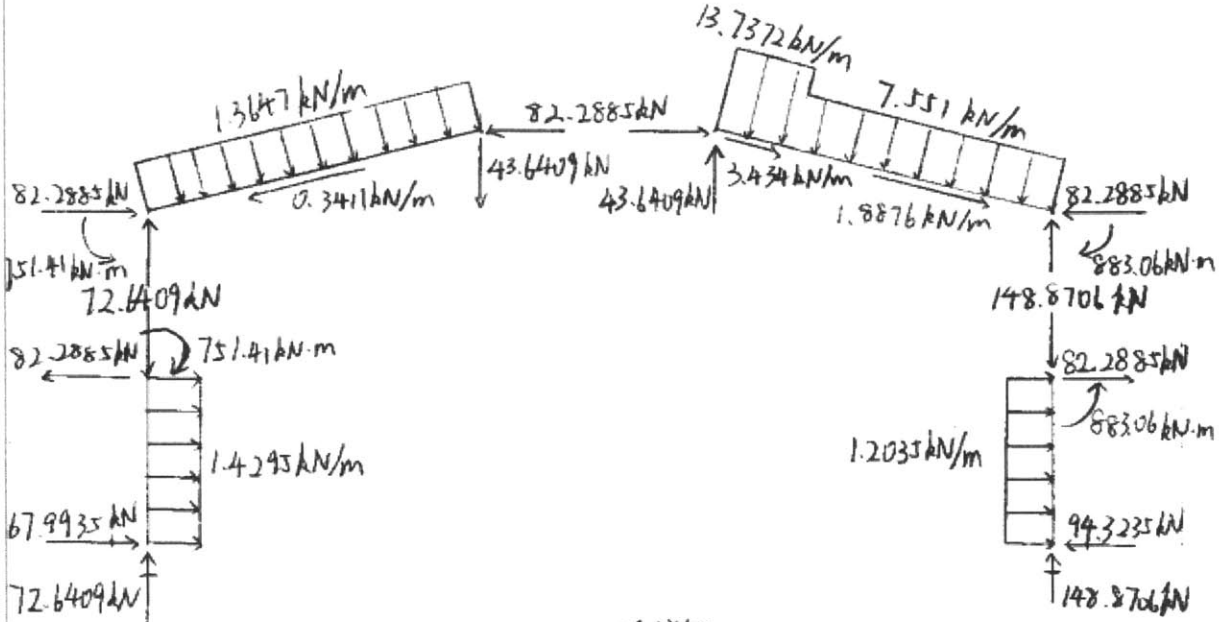
Section ②

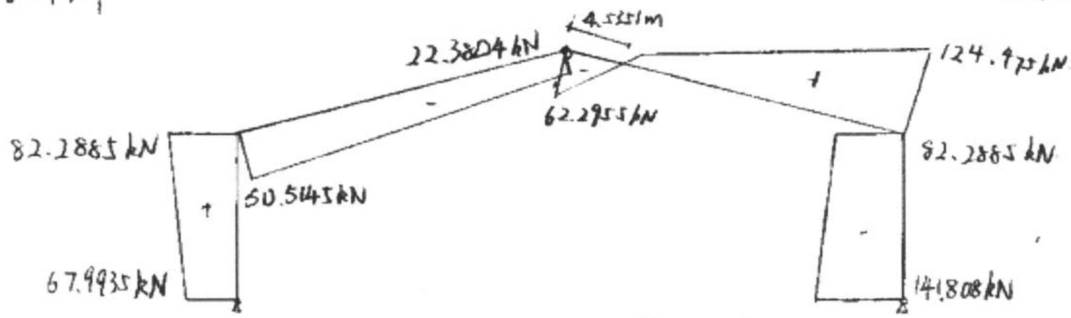
$D = 0.63$ kN/m
$S = 9.486$ kN/m
$W = -2.676$ kN/m
$\rightarrow 1.2D + 1.6S + 0.5W = 14.5956$ kN/m

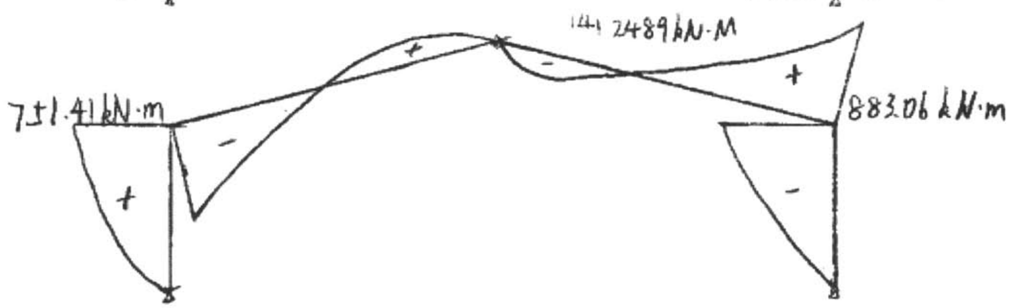
Section ③

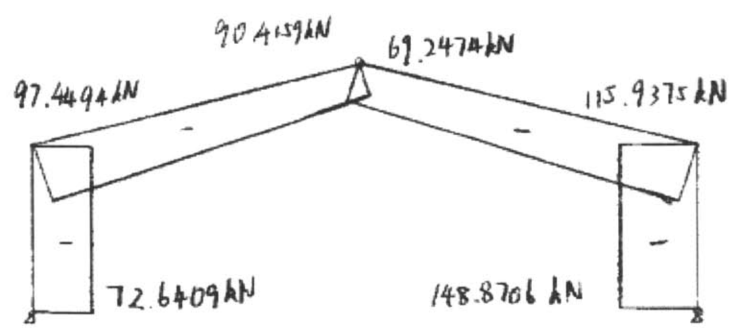
$D = 0.63$ kN/m
$S = 5.378$ kN/m
$W = -2.676$ kN/m
$\rightarrow 1.2D + 1.6S + 0.5W = 8.0228$ kN/m

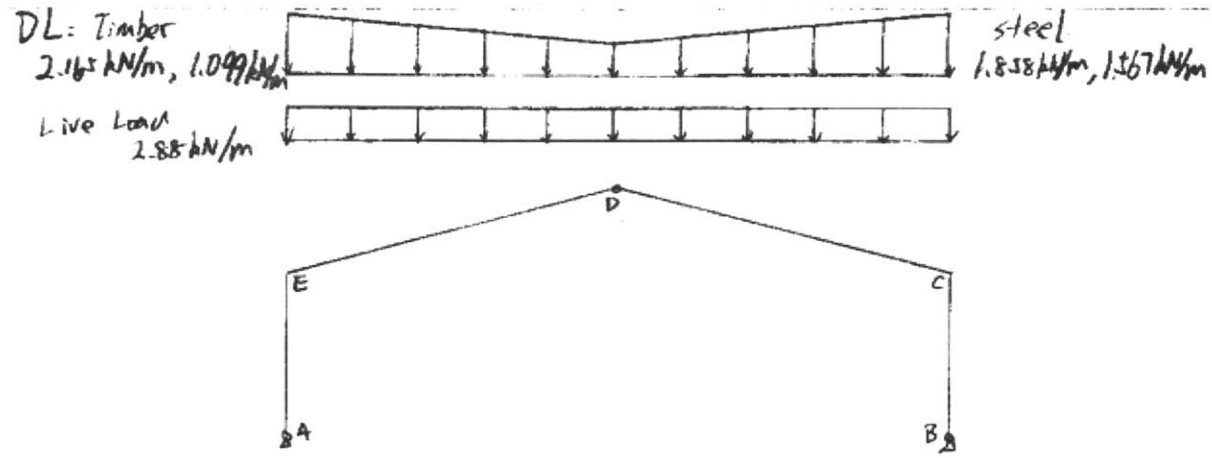



13.7372 kN/m
1.3647 kN/m
82.2885 kN
7.551 kN/m
43.6409 kN
0.3411 kN/m
3.434 kN/m
1.8876 kN/m
82.2885 kN
751.41 kN·m
883.06 kN·m
72.6409 kN
148.8706 kN
82.2885 kN
751.41 kN·m
82.2885 kN
883.06 kN·m
1.4295 kN/m
1.2035 kN/m
67.9935 kN
94.3235 kN
72.6409 kN
148.8706 kN


4.5551m
22.3804 kN
124.475 kN
62.2955 kN
82.2885 kN
82.2885 kN
50.5145 kN
67.9935 kN
141.808 kN

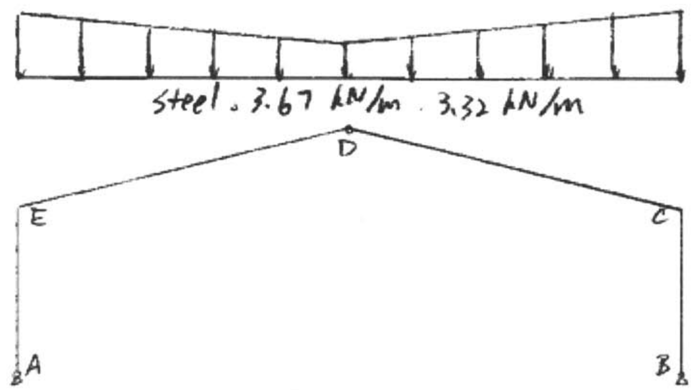

141.2489 kN·M
751.41 kN·m
883.06 kN·m

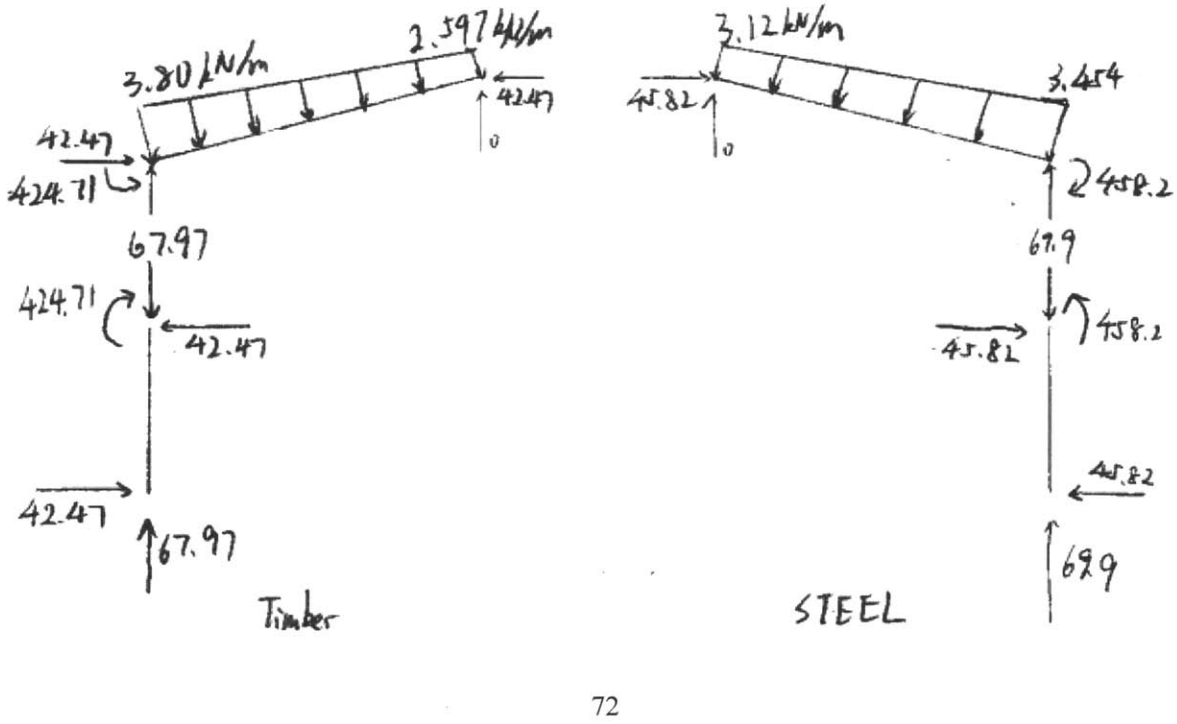

90.4159 kN
69.2474 kN
97.4494 kN
115.9375 kN
72.6409 kN
148.8706 kN

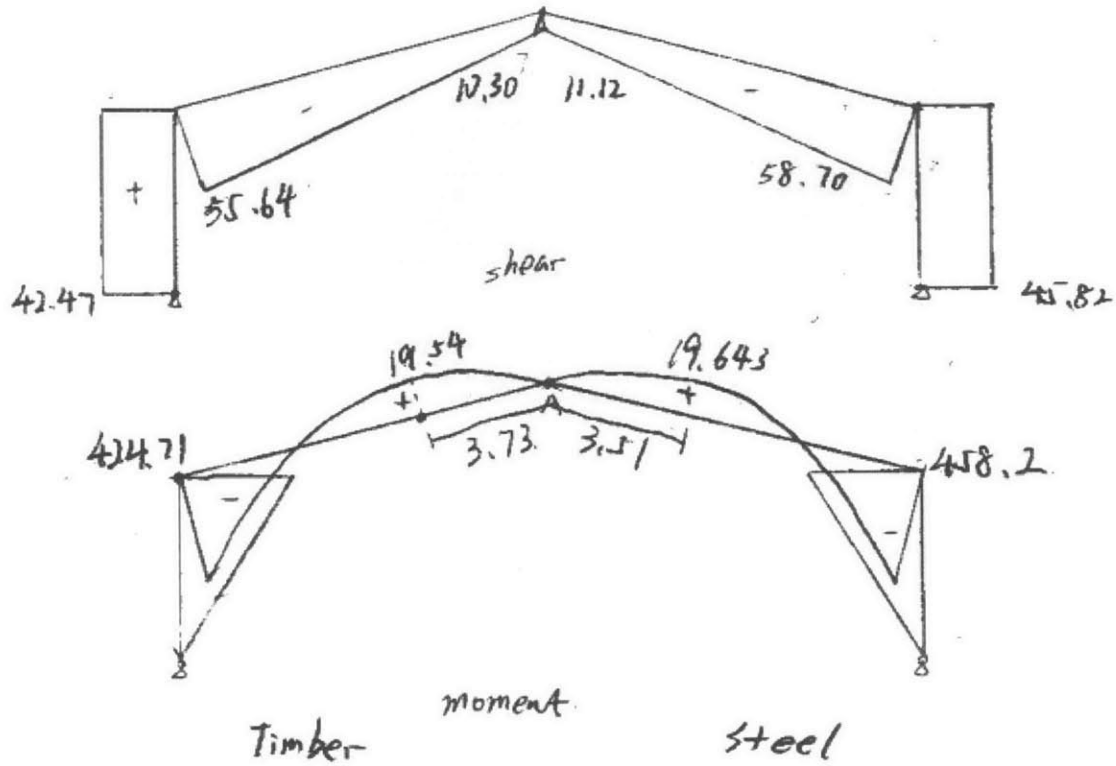


Load combination

1.2D + 0.5L: Timber: 4.038 kN/m, 2.759 kN/m.







10.30
11.12
55.64
58.70
shear
42.47
45.82
19.54
19.643
434.71
458.2
3.73
3.51
moment
Timber
Steel

Appendix F Structural Design

Timber Structure

Glued Laminated Softwood Timber Combination	
Stress Class	24F-1.8E
Combination Symbol	24F-E4
Wood Type	SP/SP
Lamination	Applied
MC	12%
x	20

Material Property (Table 5A)								
X-X			**Y-Y**			**Axial**		
F_{bx}	2400	psi	F_{by}	650	psi	F_t	1450	psi
$F_{c\perp x}$	740		$F_{c\perp y}$	650		F_c	1850	
F_{vx}	300		F_{vy}	250		E_{axial}	1800000	
E_x	1900000		E_y	1700000				
E_{xmin}	980000		E_{ymin}	880000				

Factors			
	C_{vr}	0.75	NDS Table 5A
	λ	0.8	Example 4.12
	C_t	1	Section 4.20
	C_L	1	Continuous
	C_{fu}	1.04	NDS Table 5A
	C_b	1	Section 6.8
C_V	**Roof**	0.77294163	NDS Table 5A
	Column	0.80227622	
C_p	**Roof**	0.79007684	Section 7.4
	Column	0.97261677	
C_M	F_b	1	Section 4.14
	F_t	1	
	F_v	1	
	$F_{c\perp}$	1	
	F_c	1	
	E	1	
	E_{min}	1	
φ	φ_b	0.85	Section 4.22
	φ_t	0.8	
	φ_v	0.75	
	φ_c	0.9	
	φ_s	0.85	
K_F	F_b	2.54117647	Section 4.23
	F_t	2.7	
	F_v	2.88	
	F_c	2.4	
	$Fc_{\perp}$	2.08333333	
	E_{min}	1.76470588	

Adjusted Property			
	Straight Members		
	X-X	**Y-Y**	**Axial**
F'b	3333.77	902.89	Roof
	3460.29	902.89	Column
F't			2505.6
F'v	388.8	162	
F'c⊥	741.5	975	
F'c		Roof	1952.23
		Column	2403.28
E'	1900000	1700000	1800000
E'min	1470000	1320000	
FcEn	2992.32	2686.98	Roof
	12182.52	10939.41	Column
F*cn			2470.94

	Roof Members				*Column*			
	Moment	**Shear**		**Axial**	**Moment**	**Shear**		**Axial**
	Fixed End	**Crown**	**Fixed End**		**Fixed End**	**Fixed End**	**Support**	
LRFD 3-2 (SI)	1286.58	72.099	197.094	175.69	1286.5793	122.64	134.675	274.776

Beam Dimension		
L	811.653982	in
K_e	0.8	
l_e	649.323185	in
b	8.5	in
d_s	15.125	in
d_l	49.5	in
A_s	128.5625	in^2
A_l	420.75	in^2
l_e/d	20.0951082	

Design Criteria

Maximum Moment			**Required Z**		**b**	**d**		**Z**	
Fixed End	11387.184	kip in	3415.71	in^3	8.5	49.5	in	3471.19	in^3

Shear Load			**Required A**		**b**	**d**		**A**	
Fixed End	44.31	kip	170.94	in^2	8.5	20.63	in	175.31	in^2
Crown	16.21		62.53		8.5	9.63		81.81	

Compression Load			**Require A**		**b**	**d**		**A**	
Entire Member	39.50	kip	20.23	in^2	8.5	15.13	in	128.5625	in^2

Combine Load Check					
f_{cu}	F'_{cn}	F_cE_{xn}	f_{bxu}	F'_{bxn}	
0.307	1.95	2.99	3.28	3.77	0.99

Deflection Check			
Max Allowed Deflection	3.38	in	
Observed Deflection	0.56	in	Combination 1
	0.29	in	Combination 2

Column Dimension		
L	393.70	in
K_e	0.8	
l_e	314.96	in
b	8.5	in
d_s	13.75	in
d_l	49.5	in
A_s	116.88	in^2
A_l	420.75	in^2
l_e/d	9.96	

Maximum Moment			**Required Z**		**b**	**d**		**Z**	
Fixed End	11387.18	kip in	3415.71	in^3	8.5	49.5	in	3471.19	in^3

Shear Load			**Required A**		**b**	**d**		**A**	
Fixed End	27.57	kip	106.37	in^2	8.5	13.75	in	116.88	in^2
Support	30.28	kip	116.81	in^2	8.5	13.75	in	116.88	in^2

Compression Load			**Require A**		**b**	**d**		**A**	
Entire Member	61.77	kip	25.70	in^2	8.5	9.625	in	81.81	in^2

Combine Load Check					
f_{cu}	F'_{cn}	F_cE_{xn}	f_{bxu}	F'_{bxn}	
0.53	2.49	12.18	3.28	3.91	0.92

Appendix G Analytical Method – Timber

Time		β (mm/min)		c (mm)		Beam/Column Fixed														
						A		Z		Moment				Compression				Combined load		
(min)	(hr)	Side	Bottom	Side	Bottom	mm2	in2	mm3	in3	kf	kip*in	kN*m	ratio	kf	kips	kN	ratio	fcu	fbxu	ratio
0	0.00	0	0	0	0	271451.1	420.75	56882571.7	3471.2	1	11572.1	1307.5	3.0785	1.0001	821401.7	3653776.1	63334.7	0.0308	1.0829	0.2904
5	0.08	1.26	1.09	6.30	5.44	254499.62	394.48	53091594.40	3239.85	1.0001	10801.49	1220.40	2.87	1.0001	770107.24	3425606.80	59379.56	0.03	1.16	0.31
10	0.17	1.11	0.96	11.07	9.56	241760.93	374.73	50251242.22	3066.52	1.0001	10223.65	1155.12	2.72	1.0001	731560.38	3254141.87	56407.38	0.03	1.23	0.33
15	0.25	1.03	0.89	15.39	13.29	230282.69	356.94	47698238.85	2910.73	1.0001	9704.26	1096.43	2.58	1.0001	696827.64	3099642.97	53729.29	0.04	1.29	0.35
20	0.33	0.97	0.84	19.45	16.80	219571.09	340.34	45321184.17	2765.67	1.0001	9220.68	1041.80	2.45	1.0001	664414.70	2955463.06	51230.08	0.04	1.36	0.37
25	0.42	0.93	0.81	23.32	20.14	209407.28	324.58	43070579.25	2628.33	1.0001	8762.81	990.06	2.33	1.0001	633659.35	2818656.52	48858.67	0.04	1.43	0.38
30	0.50	0.90	0.78	27.04	23.36	199668.17	309.49	40918512.89	2497.00	1.0001	8324.99	940.60	2.21	1.0001	604189.12	2687566.41	46586.35	0.04	1.51	0.41
35	0.58	0.88	0.76	30.65	26.47	190275.17	294.93	38847127.59	2370.60	1.0001	7903.59	892.99	2.10	1.0001	575766.22	2561135.10	44394.78	0.04	1.59	0.43
40	0.67	0.85	0.74	34.17	29.51	181173.96	280.82	36844048.99	2248.36	1.0001	7496.08	846.94	1.99	1.0001	548226.27	2438631.31	42271.30	0.05	1.67	0.45
45	0.75	0.84	0.72	37.60	32.48	172324.83	267.10	34900213.91	2129.74	1.0001	7100.63	802.26	1.89	1.0001	521449.11	2319520.63	40206.63	0.05	1.77	0.48
50	0.83	0.82	0.71	40.97	35.38	163697.56	253.73	33008707.84	2014.31	1.0001	6715.82	758.79	1.79	1.0001	495343.29	2203396.16	38193.73	0.05	1.87	0.50
55	0.92	0.80	0.70	44.27	38.23	155268.41	240.67	31164087.38	1901.75	1.0001	6340.55	716.39	1.69	1.0001	469836.94	2089938.29	36227.05	0.05	1.98	0.53
60	1.00	0.79	0.68	47.51	41.03	147018.23	227.88	29361959.28	1791.78	1.0001	5973.92	674.96	1.59	1.0001	444872.18	1978889.57	34302.12	0.06	2.10	0.57
65	1.08	0.78	0.67	50.71	43.79	138931.32	215.34	27598705.25	1684.18	1.0001	5615.20	634.43	1.49	1.0002	420401.46	1870038.38	32415.30	0.06	2.23	0.60
70	1.17	0.77	0.66	53.86	46.51	130994.52	203.04	25871294.84	1578.76	1.0001	5263.78	594.73	1.40	1.0002	396385.00	1763207.86	30563.49	0.06	2.38	0.65
75	1.25	0.76	0.66	56.96	49.19	123196.71	190.96	24177153.73	1475.38	1.0001	4919.12	555.79	1.31	1.0002	372789.08	1658248.05	28744.12	0.07	2.55	0.69
80	1.33	0.75	0.65	60.03	51.84	115528.32	179.07	22514068.43	1373.89	1.0001	4580.78	517.56	1.22	1.0002	349584.80	1555030.25	26954.94	0.07	2.74	0.74
85	1.42	0.74	0.64	63.06	54.46	107981.06	167.37	20880115.73	1274.18	1.0001	4248.37	480.00	1.13	1.0002	326747.04	1453442.89	25194.02	0.08	2.95	0.80
90	1.50	0.73	0.63	66.06	57.06	100547.68	155.85	19273609.24	1176.15	1.0001	3921.54	443.07	1.04	1.0002	304253.87	1353388.29	23459.67	0.08	3.20	0.87
95	1.58	0.73	0.63	69.03	59.62	93221.76	144.49	17693058.34	1079.70	1.0001	3599.99	406.74	0.96	1.0002	282085.90	1254780.29	21750.40	0.09	3.48	0.95
100	1.67	0.72	0.62	71.97	62.16	85997.64	133.30	16137135.98	984.75	1.0002	3283.46	370.98	0.87	1.0003	260225.93	1157542.33	20064.87	0.10	3.82	1.05
105	1.75	0.71	0.62	74.88	64.67	78870.20	122.25	14604653.17	891.23	1.0002	2971.69	335.76	0.79	1.0003	238658.57	1061605.93	18401.91	0.11	4.22	1.16
110	1.83	0.71	0.61	77.77	67.17	71834.90	111.34	13094538.50	799.08	1.0002	2664.47	301.04	0.71	1.0003	217369.96	966909.52	16760.44	0.12	4.70	1.30
115	1.92	0.70	0.61	80.63	69.64	64887.57	100.58	11605821.47	708.23	1.0002	2361.60	266.83	0.63	1.0004	196347.60	873397.40	15139.49	0.13	5.31	1.48
120	2.00	0.70	0.60	83.47	72.09	58024.48	89.94	10137618.90	618.64	1.0003	2062.91	233.08	0.55	1.0004	175580.10	781019.02	13538.20	0.14	6.08	1.70
130	2.17	0.69	0.59	89.08	76.94	44537.55	69.03	7259594.64	443.01	1.0004	1477.41	166.92	0.39	1.0006	134769.11	599482.72	10391.45	0.19	8.49	2.41
140	2.33	0.68	0.58	94.62	81.71	31349.94	48.59	4454759.66	271.85	1.0006	906.79	102.45	0.24	1.0009	94863.85	421975.31	7314.53	0.27	13.83	4.04
150	2.50	0.67	0.58	100.08	86.43	18441.10	28.58	1718245.53	104.85	1.0015	350.09	39.55	0.09	1.0024	55802.14	248220.23	4302.66	0.45	35.85	11.26

Appendix H Analytical Method – Steel/Protected Steel

Unprotected Steel

Time			Fire Temperature Tg	Average Tf for Time Step	Fixed end: Transfer Coefficient h	Fixed end: cp	Fixed end: Change in Steel Temperature, ΔT_s	Fixed end: Steel Temperature, T_s	Fixed end: Yield Strength	Fixed end: Moment Capactiy	Fixed end: Ratio	Max Positive Moment: Transfer Coefficient h	Max Positive Moment: cp	Max Positive Moment: Change in Steel Temperature, ΔT_s	Max Positive Moment: Steel Temperature, T_s	Max Positive Moment: Yield Strength	Max Positive Moment: Moment Capactiy	Max Positive Moment: Rorio
hr	(min)	(s)	(°C)	(°C)	(W/m²)		(°C)	(°C)	ksi	ft-kips		(W/m²)		(°C)	(°C)	ksi	ft-kips	
0	0	0	20.00					20.00	49.88	837.90	1.83				20.00	49.88	415.70	21.16
0.03	1.6667	100	192.59	106.30	29.38	439.80	112.55	132.55	48.43	813.69	1.78	29.38	439.80	96.71	116.71	48.70	405.90	20.66
0.06	3.3333	200	365.19	278.89	37.73	502.94	190.86	323.40	43.40	729.04	1.59	37.18	495.73	181.75	298.46	44.28	369.06	18.79
0.08	5	300	537.78	451.48	57.97	573.32	167.04	490.44	34.82	584.99	1.28	56.28	564.19	171.49	469.95	36.19	301.59	15.35
0.11	6.6667	400	593.33	565.56	83.41	659.50	97.96	588.40	26.49	445.00	0.97	81.28	645.44	107.15	577.09	27.63	230.32	11.73
0.14	8.3333	500	648.89	621.11	101.72	746.98	42.66	631.06	22.04	370.24	0.81	100.26	734.93	49.33	626.42	22.50	187.50	9.55
0.17	10	600	704.44	676.67	115.35	787.58	59.48	690.54	16.76	281.56	0.61	114.68	782.53	56.31	682.73	17.40	144.99	7.38
0.19	11.667	700	722.78	713.61	130.14	939.95	30.09	720.63	14.45	242.72	0.53	128.90	901.24	34.61	717.34	14.69	122.44	6.23
0.22	13.333	800	741.11	731.94	138.16	1414.49	14.76	735.39	13.39	224.92	0.49	137.61	1295.26	16.37	733.71	13.51	112.57	5.73
0.25	15	900	759.44	750.28	143.88	4607.60	19.42	754.81	12.06	202.64	0.44	143.59	3694.74	18.57	752.28	12.23	101.94	5.19
0.28	16.667	1000	771.11	765.28	150.02	1293.51	13.66	768.46	11.17	187.70	0.41	149.56	1382.51	14.57	766.85	11.28	93.98	4.78
0.31	18.333	1100	782.78	776.94	154.67	1020.67	11.06	779.52	10.48	176.01	0.38	154.37	1042.12	11.32	778.16	10.56	88.03	4.48
0.33	20	1200	794.44	788.61	158.95	912.24	11.85	791.38	9.75	163.87	0.36	158.69	922.84	11.71	789.87	9.84	82.05	4.18
0.36	21.667	1300	803.33	798.89	163.20	840.15	9.80	801.17	9.17	154.13	0.34	162.90	847.69	10.11	799.98	9.24	77.05	3.92
0.39	23.333	1400	812.22	807.78	166.85	798.94	8.61	809.79	8.68	145.78	0.32	166.62	803.35	8.74	808.72	8.74	72.83	3.71
0.42	25	1500	821.11	816.67	170.34	771.18	8.97	818.76	8.17	137.27	0.30	170.12	774.29	8.91	817.63	8.23	68.63	3.49
0.44	26.667	1600	828.52	824.81	173.80	748.05	7.90	826.66	7.73	129.95	0.28	173.57	750.71	8.06	825.68	7.79	64.91	3.30
0.47	28.333	1700	835.93	832.22	176.94	731.29	7.26	833.92	7.34	123.35	0.27	176.74	733.21	7.33	833.01	7.39	61.60	3.14
0.5	30	1800	843.33	839.63	179.99	718.15	7.45	841.37	6.95	116.70	0.25	179.81	719.69	7.42	840.43	7.00	58.31	2.97
0.53	31.667	1900	849.63	846.48	183.01	706.46	6.67	848.04	6.60	110.85	0.24	182.81	707.85	6.78	847.21	6.64	55.35	2.82
0.56	33.333	2000	855.93	852.78	185.78	697.26	6.18	854.22	6.28	105.52	0.23	185.60	698.34	6.24	853.45	6.32	52.68	2.68
0.58	35	2100	862.22	859.07	188.47	689.62	6.33	860.55	5.96	100.15	0.22	188.31	690.53	6.30	859.75	6.00	50.02	2.55
0.61	36.667	2200	867.59	864.91	191.13	682.55	5.68	866.23	5.68	95.40	0.21	190.95	683.40	5.78	865.53	5.71	47.62	2.42
0.64	38.333	2300	872.96	870.28	193.56	676.77	5.28	871.51	5.42	91.04	0.20	193.41	677.46	5.32	870.85	5.45	45.44	2.31
0.67	40	2400	878.33	875.65	195.93	671.83	5.40	876.91	5.16	86.65	0.19	195.79	672.42	5.38	876.23	5.19	43.26	2.20
0.69	41.667	2500	882.96	880.65	198.27	667.13	4.88	881.79	4.92	82.72	0.18	198.12	667.70	4.95	881.18	4.95	41.28	2.10
0.72	43.333	2600	887.59	885.28	200.42	663.18	4.55	886.34	4.71	79.10	0.17	200.29	663.66	4.59	885.77	4.74	39.47	2.01
0.75	45	2700	892.22	889.91	202.52	659.72	4.65	890.99	4.49	75.44	0.16	202.39	660.14	4.63	890.41	4.52	37.65	1.92
0.78	46.667	2800	896.48	894.35	204.62	656.38	4.38	895.37	4.29	72.03	0.16	204.48	656.79	4.42	894.83	4.31	35.95	1.83
0.81	48.333	2900	900.74	898.61	206.62	653.41	4.22	899.60	4.09	68.78	0.15	206.49	653.77	4.24	899.07	4.12	34.32	1.75
0.83	50	3000	905.00	902.87	208.60	650.70	4.27	903.87	3.90	65.52	0.14	208.48	651.03	4.26	903.33	3.92	32.71	1.67
0.86	51.667	3100	908.70	906.85	210.54	650.00	3.89	907.76	3.73	62.58	0.14	210.42	650.00	3.95	907.28	3.75	31.23	1.59
0.89	53.333	3200	912.41	910.56	212.34	650.00	3.65	911.41	3.56	59.85	0.13	212.23	650.00	3.67	910.95	3.58	29.86	1.52
0.92	55	3300	916.11	914.26	214.10	650.00	3.72	915.13	3.40	57.09	0.12	213.99	650.00	3.71	914.66	3.42	28.50	1.45
0.94	56.667	3400	919.63	917.87	215.86	650.00	3.58	918.70	3.24	54.46	0.12	215.74	650.00	3.60	918.26	3.26	27.18	1.38
0.97	58.333	3500	923.15	921.39	217.57	650.00	3.50	922.21	3.09	51.90	0.11	217.46	650.00	3.51	921.77	3.11	25.91	1.32
1	60	3600	926.67	924.91	219.27	650.00	3.52	925.73	2.94	49.35	0.11	219.17	650.00	3.52	925.29	2.96	24.64	1.25
1.03	61.667	3700	930.00	928.33	220.97	650.00	3.40	929.13	2.79	46.91	0.10	220.86	650.00	3.41	928.70	2.81	23.43	1.19
1.06	63.333	3800	933.33	931.67	222.62	650.00	3.31	932.44	2.65	44.55	0.10	222.52	650.00	3.32	932.02	2.67	22.25	1.13
1.08	65	3900	936.67	935.00	224.27	650.00	3.34	935.78	2.51	42.19	0.09	224.16	650.00	3.33	935.36	2.53	21.08	1.07
1.11	66.667	4000	939.81	938.24	225.90	650.00	3.21	938.99	2.38	39.93	0.09	225.80	650.00	3.23	938.59	2.39	19.95	1.02
1.14	68.333	4100	942.96	941.39	227.49	650.00	3.13	942.12	2.25	37.75	0.08	227.39	650.00	3.14	941.73	2.26	18.86	0.96
1.17	70	4200	946.11	944.54	229.06	650.00	3.15	945.27	2.12	35.57	0.08	228.97	650.00	3.15	944.88	2.13	17.78	0.91

Protected Steel

								Fix							MPM			
	Time		Fire Temperature Tg	Average Tg for Time Step	cp	Coefficient	Change in Steel Temperature, ΔT.	Steel Temperature, T.	Yield Strength	Moment Capactiy	Capacity ratio	cp	Coefficient	Change in Steel Temperature, ΔT.	Steel Temperature, T.	Yield Strength	Moment Capactiy	Capacity ratio
hr	(min)	(s)	(°C)	(°C)		(W/m²)	(°C)	(°C)	ksi	ft-kips			(W/m²)	(°C)	(°C)	ksi	ft-kips	
0.00	0.00	0.00	20.00					20.00	49.88	837.90	1.83				20.00	49.88	415.70	21.16
0.03	1.67	100.00	192.59	106.30	439.80	0.0001271	0.95	20.95	49.87	837.78	1.83	439.80	0.0001092	0.84	20.84	49.87	415.64	21.16
0.06	3.33	200.00	365.19	278.89	440.48	0.0001269	2.85	23.80	49.84	837.39	1.83	440.39	0.0001091	2.49	23.33	49.85	415.48	21.15
0.08	5.00	300.00	537.78	451.48	442.47	0.0001263	4.70	28.51	49.80	836.72	1.83	442.14	0.0001086	4.12	27.45	49.81	415.19	21.14
0.11	6.67	400.00	593.33	565.56	445.71	0.0001254	5.87	34.38	49.75	835.83	1.82	444.99	0.0001079	5.15	32.61	49.77	414.81	21.12
0.14	8.33	500.00	648.89	621.11	449.67	0.0001243	6.36	40.74	49.69	834.81	1.82	448.49	0.0001071	5.60	38.20	49.72	414.37	21.09
0.17	10.00	600.00	704.44	676.67	453.84	0.0001232	6.84	47.58	49.62	833.64	1.82	452.19	0.0001062	6.03	44.23	49.66	413.87	21.07
0.19	11.67	700.00	722.78	713.61	458.19	0.000122	7.11	54.68	49.54	832.35	1.82	456.08	0.0001053	6.27	50.51	49.59	413.32	21.04
0.22	13.33	800.00	741.11	731.94	462.58	0.0001208	7.17	61.85	49.46	830.98	1.81	460.02	0.0001044	6.34	56.84	49.52	412.74	21.01
0.25	15.00	900.00	759.44	750.28	466.87	0.0001197	7.22	69.07	49.38	829.52	1.81	463.89	0.0001035	6.40	63.24	49.45	412.12	20.98
0.28	16.67	1000.00	771.11	765.28	471.06	0.0001187	7.25	76.32	49.28	827.99	1.81	467.69	0.0001027	6.43	69.68	49.37	411.48	20.95
0.31	18.33	1100.00	782.78	776.94	475.14	0.0001176	7.24	83.56	49.19	826.38	1.80	471.41	0.0001019	6.43	76.11	49.29	410.80	20.91
0.33	20.00	1200.00	794.44	788.61	479.09	0.0001167	7.23	90.80	49.09	824.71	1.80	475.02	0.0001011	6.44	82.55	49.20	410.10	20.88
0.36	21.67	1300.00	803.33	798.89	482.92	0.0001157	7.21	98.01	48.99	822.98	1.80	478.54	0.0001004	6.43	88.98	49.12	409.36	20.84
0.39	23.33	1400.00	812.22	807.78	486.62	0.0001149	7.18	105.19	48.88	821.18	1.79	481.96	9.965E-05	6.41	95.39	49.02	408.61	20.80
0.42	25.00	1500.00	821.11	816.67	490.20	0.000114	7.15	112.35	48.77	819.32	1.79	485.29	9.897E-05	6.39	101.78	48.93	407.83	20.76
0.44	26.67	1600.00	828.52	824.81	493.66	0.0001132	7.12	119.47	48.65	817.40	1.78	488.51	9.832E-05	6.37	108.16	48.83	407.02	20.72
0.47	28.33	1700.00	835.93	832.22	497.01	0.0001125	7.08	126.54	48.54	815.42	1.78	491.64	9.769E-05	6.34	114.50	48.73	406.19	20.68
0.50	30.00	1800.00	843.33	839.63	500.25	0.0001117	7.04	133.59	48.42	813.39	1.78	494.69	9.709E-05	6.32	120.82	48.63	405.34	20.64
0.53	31.67	1900.00	849.63	846.48	503.40	0.000111	7.00	140.59	48.29	811.30	1.77	497.64	9.651E-05	6.29	127.11	48.53	404.46	20.59
0.56	33.33	2000.00	855.93	852.78	506.44	0.0001104	6.96	147.54	48.16	809.15	1.77	500.51	9.596E-05	6.26	133.37	48.42	403.57	20.55
0.58	35.00	2100.00	862.22	859.07	509.39	0.0001097	6.92	154.46	48.03	806.95	1.76	503.30	9.543E-05	6.23	139.59	48.31	402.65	20.50
0.61	36.67	2200.00	867.59	864.91	512.26	0.0001091	6.87	161.33	47.90	804.70	1.76	506.01	9.492E-05	6.19	145.79	48.20	401.71	20.45
0.64	38.33	2300.00	872.96	870.28	515.04	0.0001085	6.82	168.15	47.76	802.40	1.75	508.65	9.442E-05	6.16	151.94	48.08	400.74	20.40
0.67	40.00	2400.00	878.33	875.65	517.75	0.000108	6.78	174.93	47.62	800.04	1.75	511.22	9.395E-05	6.12	158.07	47.96	399.76	20.35
0.69	41.67	2500.00	882.96	880.65	520.39	0.0001074	6.73	181.66	47.48	797.63	1.74	513.73	9.349E-05	6.09	164.15	47.84	398.76	20.30
0.72	43.33	2600.00	887.59	885.28	522.96	0.0001069	6.68	188.34	47.33	795.18	1.74	516.17	9.305E-05	6.05	170.20	47.72	397.73	20.25
0.75	45.00	2700.00	892.22	889.91	525.47	0.0001064	6.63	194.97	47.18	792.67	1.73	518.55	9.262E-05	6.01	176.21	47.59	396.69	20.19
0.78	46.67	2800.00	896.48	894.35	527.92	0.0001059	6.58	201.56	47.03	790.11	1.72	520.88	9.221E-05	5.97	182.19	47.47	395.62	20.14
0.81	48.33	2900.00	900.74	898.61	530.33	0.0001054	6.54	208.09	46.88	787.51	1.72	523.16	9.181E-05	5.94	188.12	47.34	394.54	20.09
0.83	50.00	3000.00	905.00	902.87	532.68	0.0001049	6.49	214.58	46.72	784.86	1.71	525.39	9.142E-05	5.90	194.02	47.20	393.44	20.03
0.86	51.67	3100.00	908.70	906.85	534.99	0.0001045	6.44	221.03	46.56	782.15	1.71	527.57	9.104E-05	5.86	199.88	47.07	392.31	19.97
0.89	53.33	3200.00	912.41	910.56	537.26	0.000104	6.39	227.42	46.39	779.40	1.70	529.72	9.067E-05	5.82	205.71	46.93	391.17	19.91
0.92	55.00	3300.00	916.11	914.26	539.50	0.0001036	6.34	233.76	46.23	776.61	1.69	531.82	9.031E-05	5.78	211.49	46.79	390.01	19.85
0.94	56.67	3400.00	919.63	917.87	541.71	0.0001032	6.29	240.05	46.06	773.77	1.69	533.89	8.996E-05	5.75	217.24	46.65	388.83	19.79
0.97	58.33	3500.00	923.15	921.39	543.88	0.0001028	6.25	246.30	45.89	770.87	1.68	535.93	8.962E-05	5.71	222.95	46.51	387.63	19.73
1.00	60.00	3600.00	926.67	924.91	546.04	0.0001024	6.20	252.50	45.71	767.94	1.68	537.94	8.928E-05	5.67	228.62	46.36	386.41	19.67
1.03	61.67	3700.00	930.00	928.33	548.17	0.000102	6.15	258.65	45.53	764.95	1.67	539.92	8.896E-05	5.63	234.25	46.21	385.18	19.61
1.06	63.33	3800.00	933.33	931.67	550.29	0.0001016	6.11	264.76	45.35	761.92	1.66	541.88	8.863E-05	5.60	239.85	46.06	383.92	19.55
1.08	65.00	3900.00	936.67	935.00	552.40	0.0001012	6.06	270.82	45.17	758.85	1.66	543.81	8.832E-05	5.56	245.41	45.91	382.65	19.48
1.11	66.67	4000.00	939.81	938.24	554.49	0.0001008	6.01	276.84	44.98	755.72	1.65	545.73	8.801E-05	5.53	250.94	45.76	381.36	19.41
1.14	68.33	4100.00	942.96	941.39	556.58	0.0001004	5.97	282.81	44.79	752.55	1.64	547.64	8.77E-05	5.49	256.43	45.60	380.05	19.35
1.17	70.00	4200.00	946.11	944.54	558.66	0.0001	5.92	288.73	44.60	749.34	1.64	549.53	8.74E-05	5.45	261.88	45.44	378.72	19.28
1.19	71.67	4300.00	948.89	947.50	560.74	9.968E-05	5.88	294.61	44.41	746.08	1.63	551.40	8.71E-05	5.42	267.30	45.28	377.37	19.21
1.22	73.33	4400.00	951.67	950.28	562.82	9.931E-05	5.83	300.44	44.21	742.77	1.62	553.27	8.681E-05	5.38	272.68	45.11	376.00	19.14
1.25	75.00	4500.00	954.44	953.06	564.90	9.894E-05	5.78	306.22	44.01	739.42	1.61	555.13	8.652E-05	5.34	278.02	44.95	374.62	19.07

Appendix I Finite Element Analysis – Timber

Lab Fire

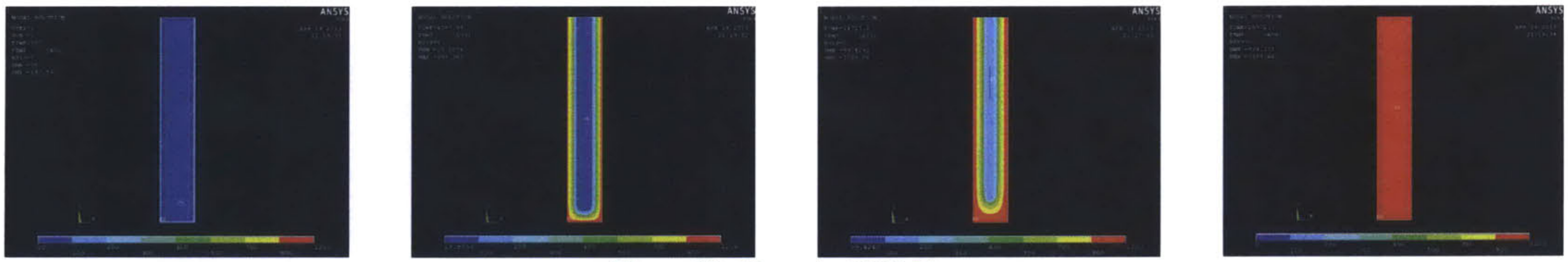


Figure 28: Fix end - E119 Fire

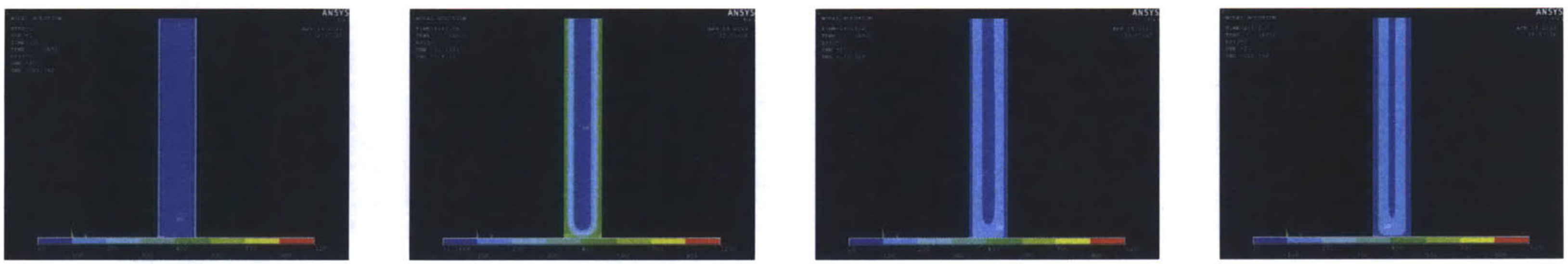


Figure 29: Fix end - Short Fire

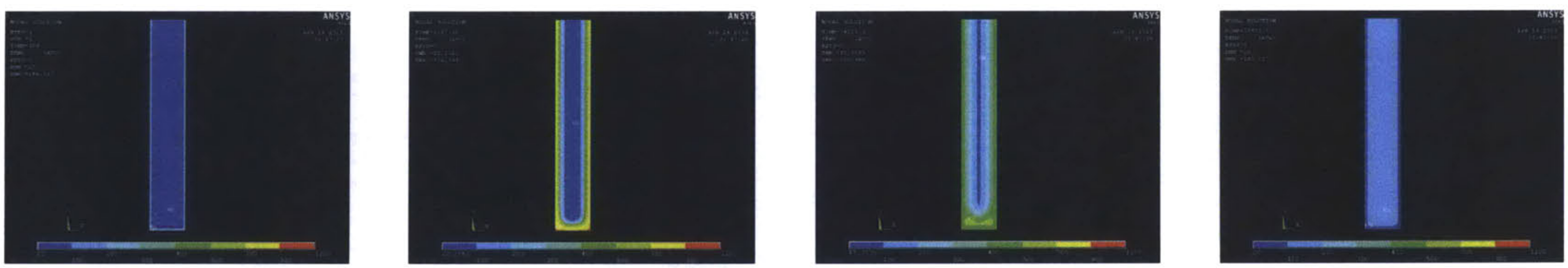


Figure 30: Fix end - Long Fire

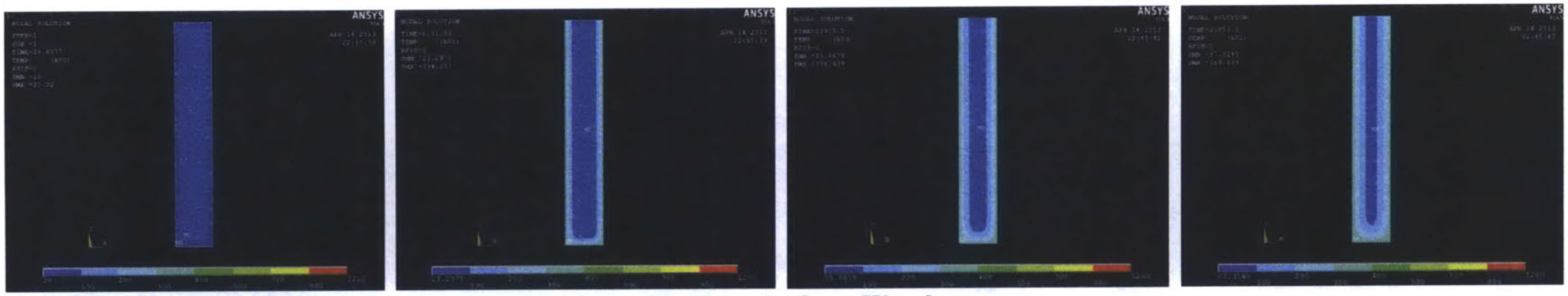


Figure 31: Fix end - Open Warehouse

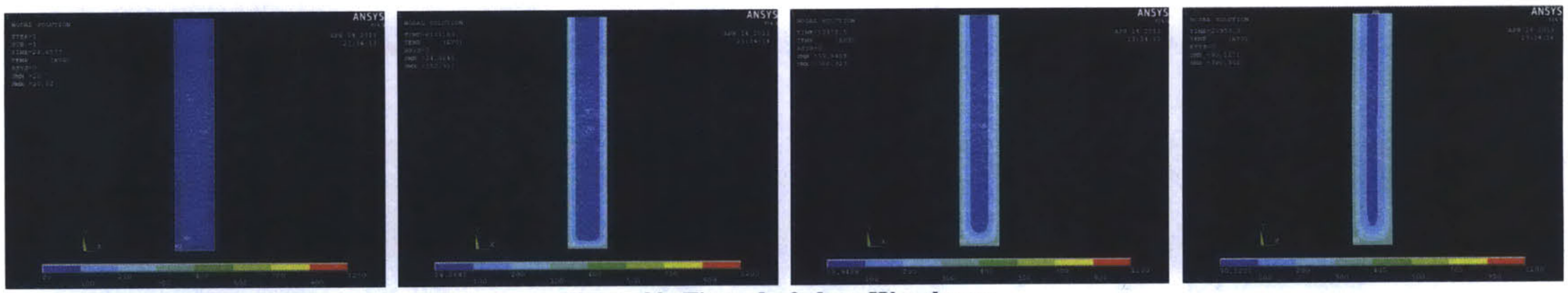


Figure 32: Fix end - 2-door Warehouse

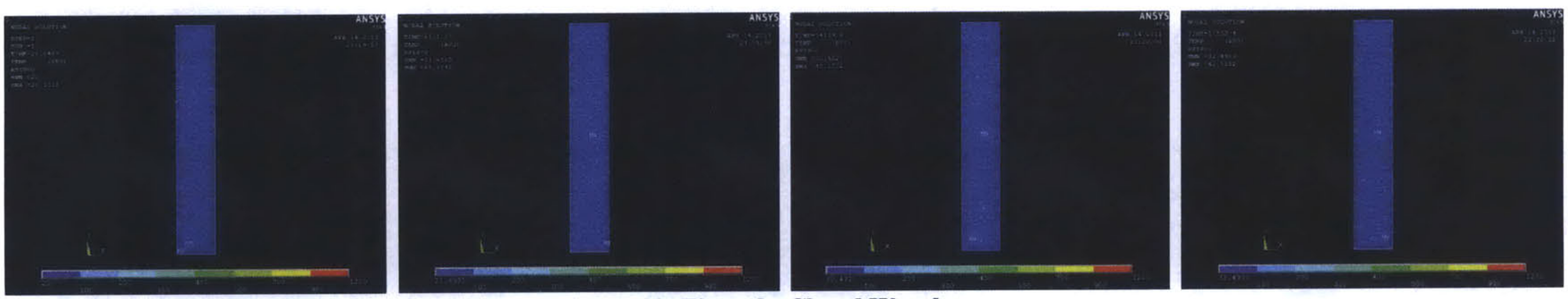


Figure 33: Fix end - Closed Warehouse

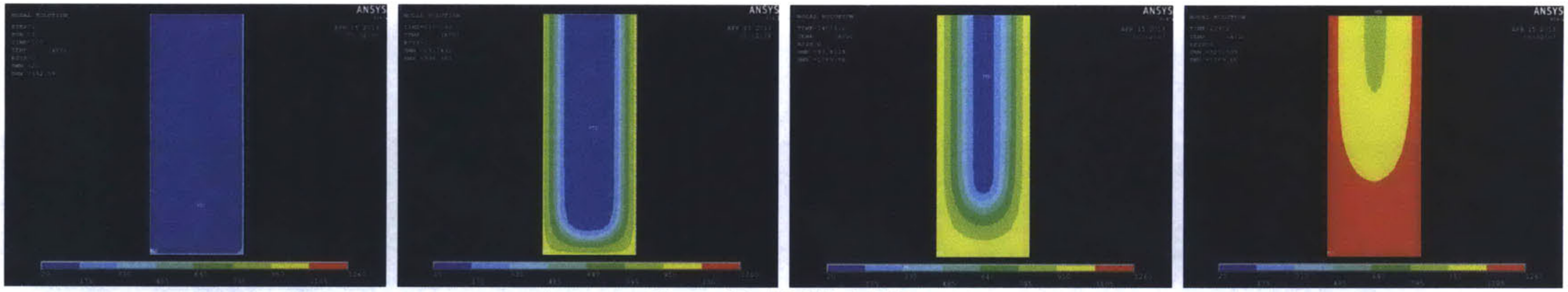


Figure 34: MPM - E119

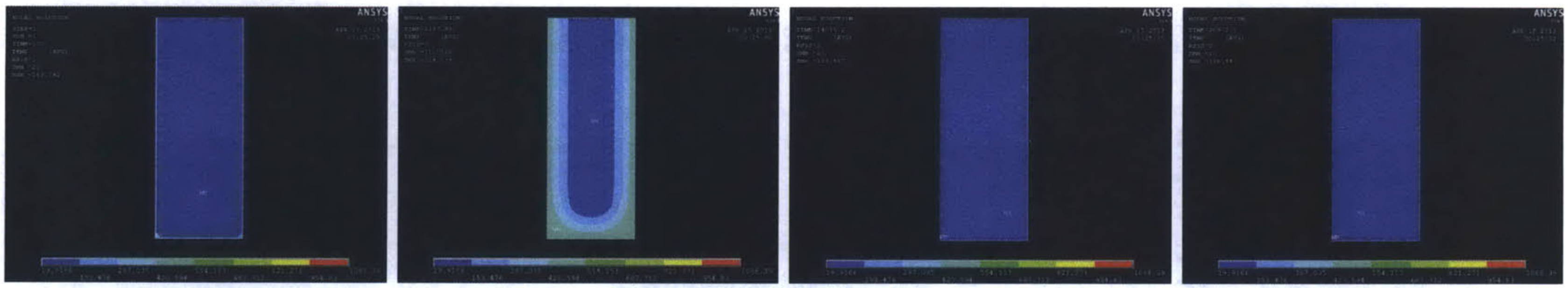


Figure 35: MPM - Short Fire

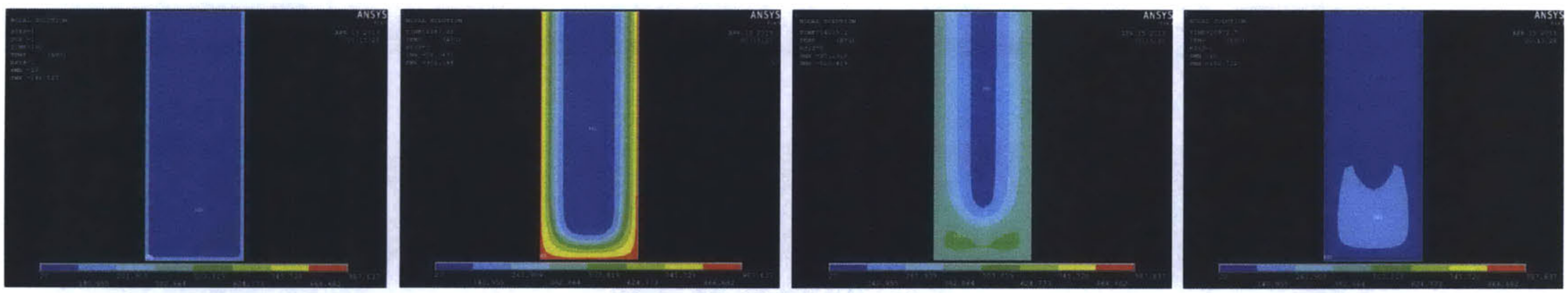


Figure 36: MPM - Long Fire

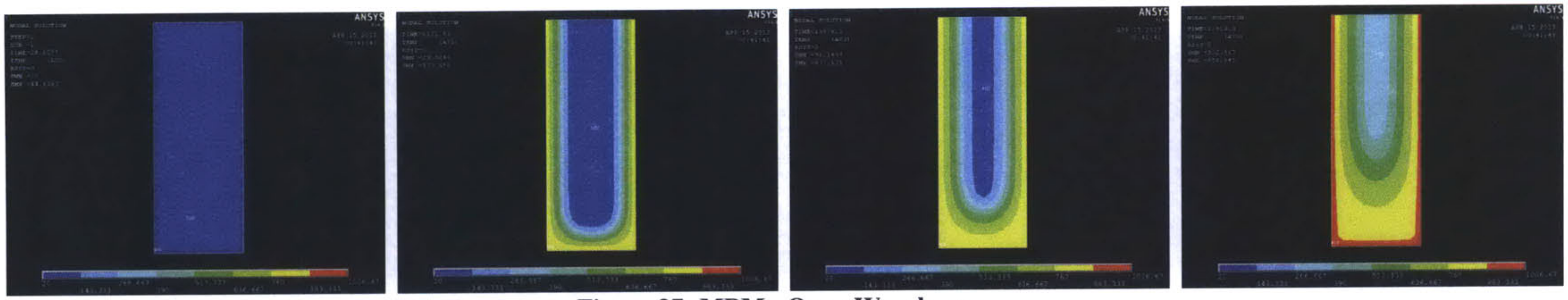


Figure 37: MPM - Open Warehouse

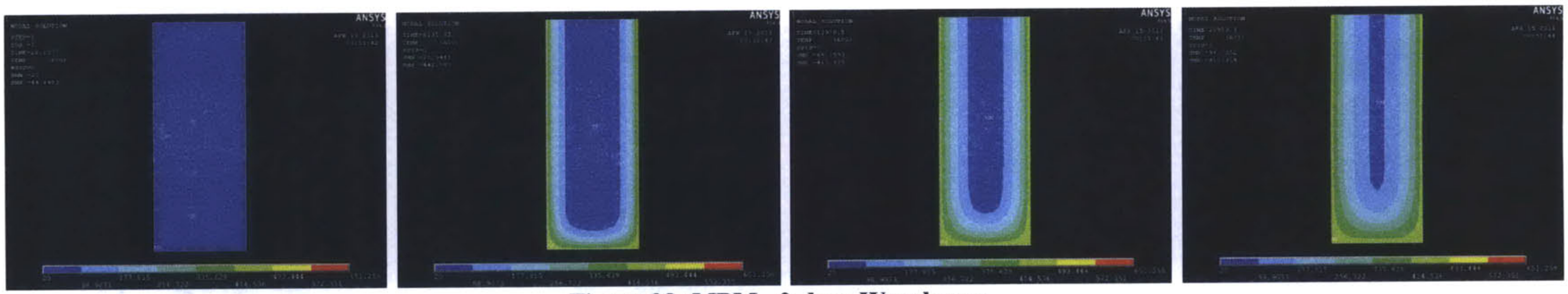


Figure 38: MPM - 2-door Warehouse

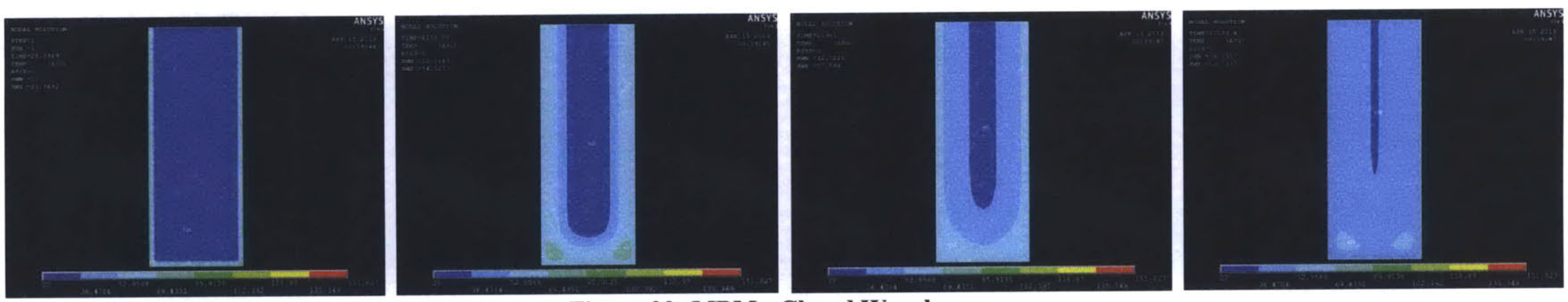


Figure 39: MPM - Closed Warehouse

Analyzing Data Generate by ANSYS – E119

14012	1089.03	1038.29	983.86	923.24	853.60	773.36	678.18	559.80	404.09	230.12	130.36	103.77	100.69	100.00	99.72	99.58	99.52	99.47	99.45	99.45	99.45	99.45	99.45	99.44	99.43	99.42	99.41	99.41	99.41	99.42
14113	1090.15	1040.38	987.04	927.69	859.61	781.31	688.98	575.57	429.37	244.58	142.19	105.42	101.34	100.51	100.20	100.04	99.97	99.92	99.90	99.89	99.89	99.90	99.89	99.88	99.87	99.86	99.85	99.85	99.85	99.85
14214	1091.27	1042.46	990.20	932.11	865.58	789.20	699.57	590.48	450.58	262.14	154.06	107.45	102.11	101.05	100.70	100.53	100.45	100.39	100.37	100.36	100.36	100.37	100.36	100.35	100.34	100.32	100.32	100.32	100.32	100.32
14315	1092.39	1044.53	993.33	936.50	871.49	796.99	709.90	604.58	469.80	283.75	173.08	110.95	102.97	101.63	101.23	101.04	100.95	100.89	100.86	100.86	100.86	100.86	100.86	100.85	100.83	100.82	100.81	100.80	100.81	100.81
14416	1093.51	1046.59	996.44	940.85	877.33	804.66	719.95	618.05	488.21	309.03	191.05	115.07	104.05	102.26	101.79	101.58	101.48	101.41	101.38	101.38	101.38	101.38	101.38	101.36	101.35	101.33	101.32	101.32	101.32	101.32
14517	1094.64	1048.64	999.53	945.15	883.11	812.20	729.76	631.11	506.45	337.72	207.98	119.78	105.29	102.98	102.37	102.14	102.03	101.96	101.93	101.92	101.92	101.92	101.92	101.91	101.89	101.87	101.86	101.86	101.86	101.86
14618	1095.77	1050.69	1002.60	949.42	888.82	819.64	739.39	643.91	524.59	366.84	223.89	131.85	106.98	103.81	103.01	102.73	102.61	102.53	102.50	102.49	102.49	102.49	102.49	102.48	102.46	102.44	102.43	102.42	102.43	102.43
14719	1096.89	1052.72	1005.65	953.65	894.46	826.99	748.89	656.53	542.64	395.80	238.79	143.91	108.96	104.74	103.74	103.36	103.21	103.13	103.09	103.08	103.08	103.09	103.08	103.07	103.05	103.03	103.02	103.01	103.01	103.01
14770	1097.45	1053.73	1007.17	955.76	897.27	830.65	753.60	662.81	551.64	410.13	246.19	151.05	110.22	105.26	104.13	103.70	103.52	103.44	103.39	103.38	103.39	103.39	103.38	103.37	103.35	103.33	103.32	103.31	103.31	103.32
14820	1098.01	1054.75	1008.69	957.85	900.07	834.28	758.29	669.03	560.46	423.26	254.72	160.72	111.99	105.81	104.53	104.06	103.85	103.75	103.70	103.69	103.70	103.70	103.69	103.68	103.66	103.64	103.62	103.62	103.62	103.62
14846	1098.29	1055.25	1009.44	958.90	901.46	836.10	760.62	672.13	564.82	429.50	259.31	165.46	112.90	106.09	104.74	104.25	104.02	103.91	103.86	103.85	103.85	103.85	103.85	103.83	103.81	103.79	103.78	103.78	103.78	103.78
14871	1098.57	1055.76	1010.20	959.94	902.85	837.90	762.95	675.21	569.11	435.47	264.21	170.12	113.85	106.39	104.95	104.44	104.20	104.07	104.02	104.01	104.01	104.01	104.01	103.99	103.97	103.95	103.94	103.93	103.93	103.93
14896	1098.85	1056.26	1010.95	960.98	904.24	839.71	765.27	678.27	573.34	441.22	269.40	174.70	114.83	106.71	105.17	104.64	104.39	104.25	104.19	104.17	104.17	104.17	104.17	104.15	104.13	104.11	104.09	104.09	104.09	104.09
14921	1099.13	1056.76	1011.70	962.02	905.62	841.50	767.58	681.32	577.49	446.80	274.88	179.21	115.85	107.03	105.39	104.83	104.57	104.44	104.37	104.35	104.35	104.35	104.34	104.32	104.29	104.27	104.25	104.25	104.25	104.25
14947	1099.41	1057.27	1012.45	963.06	907.00	843.23	769.88	684.34	581.57	452.23	280.63	183.65	116.90	107.37	105.62	105.04	104.77	104.62	104.56	104.54	104.53	104.53	104.52	104.49	104.46	104.43	104.42	104.41	104.41	104.41
14972	1099.69	1057.77	1013.20	964.10	908.38	845.08	772.17	687.33	585.59	457.54	286.64	188.04	117.99	107.72	105.86	105.24	104.96	104.81	104.74	104.72	104.72	104.71	104.70	104.68	104.65	104.61	104.59	104.58	104.58	104.58
14997	1099.97	1058.27	1013.95	965.13	909.75	846.86	774.45	690.31	589.55	462.77	292.92	192.36	119.11	108.08	106.10	105.45	105.16	105.01	104.93	104.91	104.91	104.90	104.89	104.86	104.83	104.80	104.78	104.76	104.76	104.76
15022	1100.27	1058.78	1014.70	966.16	911.12	848.64	776.73	693.26	593.45	467.92	299.46	196.65	120.73	108.47	106.36	105.66	105.36	105.20	105.13	105.10	105.10	105.09	105.08	105.05	105.02	104.99	104.96	104.95	104.95	104.94
15048	1100.57	1059.29	1015.45	967.19	912.49	850.41	778.99	696.18	597.30	473.03	306.27	200.93	122.57	108.87	106.63	105.88	105.57	105.40	105.33	105.30	105.30	105.29	105.27	105.25	105.21	105.18	105.15	105.14	105.14	105.13
15073	1100.88	1059.80	1016.20	968.22	913.85	852.17	781.24	699.08	601.10	478.09	313.32	205.21	125.47	109.32	106.91	106.11	105.78	105.61	105.53	105.50	105.49	105.49	105.47	105.44	105.41	105.37	105.35	105.33	105.33	105.33
15098	1101.18	1060.32	1016.95	969.25	915.21	853.93	783.48	701.96	604.86	483.12	320.64	209.52	128.43	109.78	107.19	106.34	105.99	105.82	105.73	105.70	105.70	105.69	105.67	105.65	105.61	105.57	105.54	105.53	105.52	105.52
15123	1101.48	1060.83	1017.70	970.27	916.57	855.69	785.71	704.82	608.59	488.14	328.21	213.83	131.43	110.25	107.49	106.59	106.21	106.03	105.94	105.91	105.90	105.89	105.88	105.85	105.81	105.77	105.75	105.73	105.72	105.72
15149	1101.79	1061.35	1018.45	971.30	917.92	857.44	787.93	707.66	612.27	493.16	335.99	218.16	134.47	110.75	107.79	106.86	106.44	106.24	106.15	106.12	106.11	106.10	106.09	106.06	106.02	105.98	105.96	105.94	105.94	105.94
15174	1102.10	1061.86	1019.20	972.32	919.28	859.18	790.15	710.47	615.94	498.17	343.80	222.45	137.52	111.27	108.10	107.13	106.69	106.47	106.37	106.34	106.34	106.33	106.32	106.29	106.26	106.22	106.19	106.18	106.17	106.17
15199	1102.40	1062.38	1019.95	973.34	920.63	860.92	792.35	713.27	619.57	503.18	351.53	226.71	141.09	111.89	108.43	107.40	106.95	106.72	106.62	106.59	106.58	106.57	106.56	106.53	106.50	106.46	106.43	106.41	106.41	106.41
15224	1102.70	1062.89	1020.70	974.37	921.97	862.65	794.55	716.05	623.18	508.17	359.22	230.94	144.83	112.56	108.75	107.68	107.21	106.98	106.87	106.84	106.83	106.82	106.81	106.78	106.74	106.70	106.68	106.66	106.65	106.66
15250	1103.01	1063.41	1021.45	975.39	923.31	864.38	796.73	718.82	626.78	513.15	366.90	235.18	149.75	113.44	109.09	107.97	107.48	107.24	107.13	107.09	107.08	107.08	107.06	107.03	107.00	106.96	106.93	106.91	106.90	106.91
15275	1103.31	1063.92	1022.20	976.40	924.65	866.10	798.91	721.57	630.35	518.12	374.55	239.41	154.57	114.36	109.44	108.27	107.76	107.51	107.39	107.35	107.34	107.33	107.32	107.29	107.26	107.21	107.18	107.16	107.16	107.16
15300	1103.61	1064.44	1022.95	977.42	925.99	867.82	801.07	724.30	633.90	523.08	382.20	243.63	159.31	115.30	109.80	108.57	108.04	107.78	107.66	107.62	107.61	107.60	107.58	107.56	107.52	107.48	107.44	107.43	107.42	107.42
15325	1103.92	1064.95	1023.69	978.44	927.32	869.53	803.23	727.02	637.45	528.03	389.85	247.81	163.97	116.28	110.17	108.88	108.33	108.06	107.93	107.89	107.88	107.87	107.85	107.83	107.79	107.74	107.71	107.69	107.69	107.69
15376	1104.52	1065.98	1025.19	980.46	929.98	872.93	807.51	732.42	644.47	537.86	404.92	256.35	172.98	118.51	110.95	109.52	108.93	108.64	108.51	108.46	108.44	108.44	108.42	108.39	108.35	108.30	108.27	108.25	108.24	108.25
15426	1105.13	1067.01	1026.67	982.48	932.62	876.31	811.76	737.77	651.43	547.49	418.67	266.18	181.92	123.62	111.87	110.19	109.55	109.24	109.10	109.05	109.03	109.02	109.00	108.97	108.93	108.89	108.85	108.83	108.82	108.83
15477	1105.74	1068.03	1028.16	984.48	935.25	879.66	815.98	743.08	658.31	556.86	431.46	277.17	190.84	128.90	112.85	110.88	110.20	109.86	109.71	109.66	109.64	109.63	109.61	109.58	109.54	109.49	109.45	109.43	109.42	109.43
15578	1106.96	1070.07	1031.11	988.47	940.46	886.31	824.34	753.53	671.69	574.59	455.10	304.21	209.64	146.01	116.32	112.41	111.58	111.20	111.02	110.96	110.94	110.92	110.90	110.87	110.82	110.77	110.73	110.71	110.70	110.71
15679	1108.18	1072.11	1034.05	992.43	945.62	892.89	832.59	763.78	684.70	591.58	477.99	336.26	229.78	163.21	125.01	114.29	113.05	112.61	112.42	112.34	112.31	112.30	112.27	112.24	112.19	112.14	112.10	112.07	112.06	112.07
15780	1109.39	1074.14	1036.96	996.36	950.73	899.39	840.73	773.85	697.38	608.03	500.37	368.45	249.53	180.84	139.01	117.58	114.65	114.11	113.89	113.80	113.77	113.75	113.72	113.69	113.64	113.58	113.54	113.51	113.50	113.50
15881	1110.60	1076.16	1039.87	1000.27	955.80	905.82	848.76	783.75	709.80	624.06	522.20	399.86	269.99	199.07	153.94	127.16	117.00	115.71	115.44	115.34	115.30	115.27	115.24	115.21	115.16	115.10	115.05	115.02	115.01	115.02
15982	1111.82	1078.18	1042.75	1004.14	960.82	912.18	856.70	793.53	721.97	639.64	543.02	427.95	296.74	218.75	169.62	140.28	127.76	119.89	117.26	116.95	116.90	116.87	116.84	116.80	116.75	116.69	116.64	116.61	116.60	116.60
16032	1112.43	1079.16	1044.19	1006.07	963.32	915.34	860.64	798.39	727.99	647.32	553.17	441.45	312.00	229.09	177.67	147.04	133.26	125.03	119.52	118.20	117.85	117.72	117.66	117.61	117.56	117.50	117.45	117.42	117.41	117.41
16058	1112.73	1079.69	1044.91	1007.03	964.57	916.92	862.61	800.81	730.98	651.13	558.17	448.08	320.05	234.38	181.75	150.48	136.05	127.62	121.58	118.99	118.55	118.35	118.21	118.12	118.03	117.94	117.87	117.83	117.82	117.82
16083	1113.04	1080.19	1045.63	1007.99	965.81	918.49	864.57	803.22	733.96	654.91	563.12	454.62	328.26	239.72	185.89	153.98	138.87	130.22	124.17	121.17	119.44	119.07	118.93	118.83	118.74	118.62	118.47	118.39	118.35	118.34
16096	1113.19	1080.44	1045.99	1008.47	966.44	919.28	865.55	804.43	735.45	656.80	565.58	457.87	332.36	242.38	187.98	155.75	140.29	131.53	125.47	122.45	120.37	119.53	119.31	119.20	119.10	118.98	118.83	118.74	118.70	118.67
16102	1113.26	1080.56	1046.17	1008.71	966.75	919.67	866.04	805.03	736.19	657.74	566.80	459.49	334.42	243.71	189.03	156.63	141.01	132.18	126.12	123.09	120.97	119.87	119.54	119.41	119.30	119.17	119.01	118.92	118.88	118.85
16108	1113.34	1080.69	1046.35	1008.95	967.06	920.07	866.53	805.63	736.94	658.68	568.02	461.10	336.47	245.03	190.08	157.52	141.72	132.83	126.77	123.72	121.61	120.47	119.90	119.69	119.55	119.39	119.21	119.12	119.07	119.05
16115	1113.41	1080.82	1046.53	1009.19	967.37	920.46	867.02	806.23	737.68	659.61	569.24	462.71	338.53	246.36	191.14	158.42	142.44	133.49	127.42	124.36	122.25	121.11	120.54	120.30	119.99	119.71	119.48	119.36	119.31	119.29
16118	1113.45	1080.88	1046.61	1009.31	967.52	920.65	867.26	806.53	738.05	660.08	569.85	463.51	339.56	247.02	191.67	158.86	142.80	133.82	127.74	124.68	122.57	121.43	120.86	120.62	120.30	119.93	119.64	119.50	119.44	119.43
16121	1113.49	1080.94	1046.70	1009.43	967.68	920.85	867.51	806.83	738.42	660.55	570.45	464.31	340.59	247.69	192.20	159.31	143.16	134.15	128.07	125.00	122.89	121.75	121.18	120.94	120.61	120.24	119.85	119.67	119.61	119.60
16127	1113.57	1081.07	1046.88	1009.67	967.99	921.24	868.00	807.43	739.15	661.48	571.66	465.91	342.65	249.01	193.26	160.21	143.89	134.81	128.72	125.64	123.53	122.39	121.82	121.58	121.25	120.87	120.49	120.31	120.24	120.23
16133	1113.64	1081.19	1047.06	1009.91	968.30	921.63	868.48	808.03	739.89	662.41	572.87	467.50	344.71	250.33	194.33	161.12	144.61	135.47	129.37	126.28	124.17	123.03	122.46	122.21	121.89	121.51	121.13	120.94	120.88	120.87
16146	1113.79	1081.44	1047.42	1010.39	968.92	922.41	869.46	809.23	741.36	664.27	575.27	470.67	348.84	252.97	196.48	162.93	146.07	136.79	130.67	127.56	125.45	124.30	123.73	123.48	123.16	122.78	122.40	122.22	122.15	122.14
16184	1114.25	1082.19	1048.49	1011.82	970.77	924.75	872.37	812.80	745.75	669.77	582.35	480.05	361.28	260.89	203.09	168.45	150.57	140.82	134.61	131.40	129.29	128.14	127.56	127.30	126.97	126.60	126.22	126.03	125.96	125.95
16285	1115.39	1084.14	1051.31	1015.60	975.66	930.92	880.04	822.22	757.23	684.06	600.59	504.15	393.65	284.16	222.31	183.96	163.51	152.13	145.38	141.86	139.67	138.47	137.86	137.55	137.22	136.85	136.49	136.29	136.20	136.18
16386	1116.51	1086.07	1054.09	1019.34	980.50	937.03	887.63	831.52	768.51	698.00	618.22	527.11	423.56	314.93	244.21	200.71	177.31	164.19	156.60	152.62	150.27	148.99	148.32	147.96	147.62	147.25	146.89	146.68	146.59	146.57
16487	1117.64	1087.98	1056.85	1023.04	985.29	943.07	895.12	840.69	779.59	711.59	635.26	548.98	451.72	347.61	266.86	219.05	192.01	177.12	168.46	163.83	161.22	159.80	159.05	158.63	158.27	157.89	157.54	157.32	157.22	157.19
16588	1118.76	1089.87	1059.58	1026.71	990.03	949.04	902.53	849.75	790.51	724.88	651.76	569.89	478.58	380.72	231.74	239.74	208.01	190.79	181.06	175.70	172.67	171.04	170.16	169.68	169.28	168.90	168.55	168.32	168.21	168.17
16689	1119.88	1091.76	1062.30	1030.35	994.72	954.95	909.85	858.70	801.27	737.88	667.76	589.94	504.01	411.92	322.84	262.94	225.98	205.49	194.27	188.11	184.68	182.83	181.83	181.25	180.82	180.42	180.08	179.84	179.71	179.67
16790	1121.00	1093.64	1064.99	1033.95	999.37	960.80	917.09	867.54	811.89	750.61	683.30	609.20	528.12	441.54	355.75	287.67	246.74	221.85	208.46	201.21	197.19	195.01	193.82	193.13	192.64	192.23	191.88	191.64	191.51	191.46
16891	1122.12	1095.51	1067.66	1037.53	1003.98	966.58	924.24	876.27	822.39	763.10	698.40	627.73	551.05	469.63	388.05	316.91	270.48	240.72	224.13	215.34	210.54	207.92	206.47	205.64	205.07	204.63	204.27	204.01	203.87	203.82
16992	1123.24	1097.37	1070.32	1041.07	1008.54	972.31	931.31	884.88	832.74	775.35	713.10	645.60	572.92	496.23	419.04	348.81	296.69	263.44	242.18	230.93	225.00	221.80	220.03	219.01	218.34	217.85	217.46	217.20	217.04	216.98
17093	1124.36	1099.22	1072.96	1044.59	1013.06	977.97	938.30	893.39	842.95	787.39	727.43	662.86	593.83	521.45	448.55	380.71	325.65	283.06	264.23	249.05	241.08	236.93	234.70	233.44	232.64	232.08	231.66	231.37	231.20	231.13
17194	1125.49	1101.08	1075.59	1048.08	1017.53	983.58	945.20	901.79	853.03	799.25	741.42	679.56	613.88	545.41	476.55	411.66	356.55	315.79	290.06	272.00	260.56	254.42	251.19	249.42	248.36	247.65	247.15	246.81	246.60	246.52
17295	1126.61	1102.92	1078.20	1051.55	1021.97	989.12	952.03	910.09	862.97	810.95	755.09	695.74	633.14	568.23	503.11	441.30	387.39	345.13	315.86	297.67	285.45	277.36	272.21	269.29	267.58	266.52	265.81	265.34	265.05	264.93
17396	1127.74	1104.75	1080.80	1054.98	1026.37	994.61	958.78	918.28	872.78	822.51	768.49	711.46	651.67	590.02	528.34	469.55	417.40	375.10	343.97	323.09	310.28	301.91	296.52	293.30	291.38	290.13	289.42	288.92	288.62	288.49
17497	1128.94	1106.63	1083.41	1058.41	1030.73	1000.05	965.45	926.36	882.46	833.89	781.63	726.74	669.55	610.88	552.35	496.44	446.28	404.63	372.87	350.51	335.66	326.06	320.42	317.01	314.92	313.61	312.78	312.24	311.93	311.78
17598	1130.17	1108.52	1086.02	1061.83	1035.07	1005.43	972.05	934.35	892.01	845.13	794.55	741.63	686.83	630.89	575.25	522.05	473.93	433.31	401.53	378.42	362.56	352.08	345.58	341.53	338.95	337.32	336.29	335.65	335.27	335.09

Char thickness

Fix Connection										Maximum Positive Moment									
Bottom		Sides		A		Z		M	Ratio	Bottom		Sides		A		Z		M	Ratio
Time	Thickness	Time	Thickness	mm	in	mm	in	kN*m		Time	Thickness	Time	Thickness	mm	in	mm	in	kN*m	
ASTM E119 Fire																			
200	0.00	200	0.00	2.7E+05	4.2E+02	5.7E+07	3.5E+03	1.3E+03	3.08	200	0.00	200	0.00	1.2E+05	1.8E+02	1.1E+07	6.5E+02	2.4E+02	12.44
1682	14.79	1682	15.42	2.3E+05	3.6E+02	4.8E+07	2.9E+03	1.1E+03	2.58	1634	14.64	1634	14.79	9.8E+04	1.5E+02	8.6E+06	5.3E+02	2.0E+02	10.14
3977	29.58	3977	30.19	1.9E+05	3.0E+02	3.9E+07	2.4E+03	8.9E+02	2.11	3887	29.28	3887	28.69	8.1E+04	1.3E+02	6.9E+06	4.2E+02	1.6E+02	8.11
4078	30.18	4078	30.84	1.9E+05	2.9E+02	3.9E+07	2.4E+03	8.9E+02	2.09	4007	29.98	4007	29.43	8.0E+04	1.2E+02	6.8E+06	4.2E+02	1.6E+02	8.01
6463	44.37	6463	41.10	1.6E+05	2.5E+02	3.2E+07	2.0E+03	7.5E+02	1.76	6400	43.92	6400	39.26	6.8E+04	1.1E+02	5.6E+06	3.4E+02	1.3E+02	6.54
7662	44.37	7662	46.26	1.5E+05	2.3E+02	3.0E+07	1.8E+03	6.9E+02	1.62	7570	52.06	7570	44.07	6.3E+04	9.7E+01	4.9E+06	3.0E+02	1.1E+02	5.82
8559	59.16	8559	49.18	1.4E+05	2.2E+02	2.8E+07	1.7E+03	6.3E+02	1.49	8505	58.56	8505	46.97	5.9E+04	9.1E+01	4.5E+06	2.8E+02	1.0E+02	5.35
10225	73.95	10225	54.61	1.3E+05	2.0E+02	2.4E+07	1.5E+03	5.5E+02	1.30	10163	73.20	10163	52.11	5.2E+04	8.1E+01	3.8E+06	2.3E+02	8.7E+01	4.44
11563	88.74	11563	58.97	1.1E+05	1.8E+02	2.1E+07	1.3E+03	4.9E+02	1.14	11509	87.84	11509	56.28	4.7E+04	7.3E+01	3.1E+06	1.9E+02	7.2E+01	3.66
12396	99.59	12396	61.68	1.1E+05	1.7E+02	1.9E+07	1.2E+03	4.4E+02	1.04	12292	97.92	12292	58.71	4.4E+04	6.8E+01	2.7E+06	1.7E+02	6.2E+01	3.18
12699	103.53	12699	62.85	1.0E+05	1.6E+02	1.8E+07	1.1E+03	4.2E+02	1.00	12646	102.48	12646	59.98	4.2E+04	6.5E+01	2.5E+06	1.5E+02	5.8E+01	2.96
13608	118.32	13608	66.36	9.5E+04	1.5E+02	1.6E+07	9.8E+02	3.7E+02	0.87	13605	117.12	13605	63.43	3.8E+04	5.9E+01	2.0E+06	1.2E+02	4.5E+01	2.29
14416	133.11	14416	69.49	8.6E+04	1.3E+02	1.4E+07	8.4E+02	3.2E+02	0.74	14312	131.76	14312	65.97	3.4E+04	5.3E+01	1.5E+06	8.9E+01	3.4E+01	1.72
15502	147.90	15502	73.68	7.6E+04	1.2E+02	1.1E+07	6.7E+02	2.5E+02	0.60	15019	146.40	15019	68.52	3.1E+04	4.8E+01	1.0E+06	6.1E+01	2.3E+01	1.17
15578	162.69	15578	73.98	7.4E+04	1.2E+02	9.9E+06	6.1E+02	2.3E+02	0.54	15524	161.04	15524	70.33	2.9E+04	4.4E+01	5.9E+05	3.6E+01	1.3E+01	0.69
15982	177.48	15982	75.54	7.0E+04	1.1E+02	8.3E+06	5.1E+02	1.9E+02	0.45	15979	175.68	15979	71.97	2.6E+04	4.1E+01	2.0E+05	1.2E+01	4.5E+00	0.23
16285	192.27	16285	76.71	6.7E+04	1.0E+02	6.9E+06	4.2E+02	1.6E+02	0.37	16282	190.32	16282	73.06	2.5E+04	3.8E+01	0.0E+00	0.0E+00	0.0E+00	0.00
16386	197.20	16386	77.10	6.5E+04	1.0E+02	6.4E+06	3.9E+02	1.5E+02	0.35	16363	194.23	16363	73.35	2.4E+04	3.7E+01	0.0E+00	0.0E+00	0.0E+00	0.00
16588	207.06	16588	80.53	5.8E+04	8.9E+01	4.5E+06	2.7E+02	1.0E+02	0.24	16585	204.96	16585	77.28	2.1E+04	3.2E+01	0.0E+00	0.0E+00	0.0E+00	0.00
16790	221.85	16790	83.95	5.0E+04	7.7E+01	2.2E+06	1.3E+02	5.1E+01	0.12	16787	219.60	16787	80.85	1.7E+04	2.7E+01	0.0E+00	0.0E+00	0.0E+00	0.00
16992	236.64	16992	87.38	4.2E+04	6.5E+01	0.0E+00	0.0E+00	0.0E+00	0.00	16989	234.24	16989	84.42	1.4E+04	2.2E+01	0.0E+00	0.0E+00	0.0E+00	0.00
17093	251.43	17093	89.09	3.8E+04	5.9E+01	0.0E+00	0.0E+00	0.0E+00	0.00	17090	248.88	17090	86.20	1.3E+04	2.0E+01	0.0E+00	0.0E+00	0.0E+00	0.00
17194	266.22	17194	90.81	3.4E+04	5.3E+01	0.0E+00	0.0E+00	0.0E+00	0.00	17191	256.20	17191	87.99	1.1E+04	1.8E+01	0.0E+00	0.0E+00	0.0E+00	0.00
17295	290.87	17295	92.52	3.0E+04	4.6E+01	0.0E+00	0.0E+00	0.0E+00	0.00	17292	263.52	17292	89.78	1.0E+04	1.6E+01	0.0E+00	0.0E+00	0.0E+00	0.00

17497	340.17	17497	92.52	2.8E+04	4.4E+01	0.0E+00	0.0E+00	0.0E+00	0.00	17393	307.44	17393	91.56	7.7E+03	1.2E+01	0.0E+00	0.0E+00	0.0E+00	0.00
Long Fire																			
200	0.00	200	0.00	2.7E+05	4.2E+02	5.7E+07	3.5E+03	1.3E+03	3.08	200	0.00	200	0.00	1.2E+05	1.8E+02	1.1E+07	6.5E+02	2.4E+02	12.44
2066	14.79	2066	15.42	2.3E+05	3.6E+02	4.8E+07	2.9E+03	1.1E+03	2.58	2047	14.64	2047	14.79	9.8E+04	1.5E+02	8.6E+06	5.3E+02	2.0E+02	10.14
4908	29.58	4908	29.82	1.9E+05	3.0E+02	3.9E+07	2.4E+03	9.0E+02	2.12	4876	29.28	4876	28.45	8.2E+04	1.3E+02	6.9E+06	4.2E+02	1.6E+02	8.13
5110	30.68	5110	30.84	1.9E+05	2.9E+02	3.9E+07	2.4E+03	8.9E+02	2.09	5078	30.40	5078	29.43	8.0E+04	1.2E+02	6.8E+06	4.1E+02	1.6E+02	7.99
7617	44.37	7617	40.17	1.6E+05	2.5E+02	3.3E+07	2.0E+03	7.6E+02	1.78	7516	43.92	7516	38.25	6.9E+04	1.1E+02	5.6E+06	3.4E+02	1.3E+02	6.64
9254	55.76	9254	46.26	1.5E+05	2.3E+02	2.9E+07	1.8E+03	6.7E+02	1.58	7685	58.56	7685	38.87	6.7E+04	1.0E+02	5.2E+06	3.2E+02	1.2E+02	6.09
9742	59.16	9742	48.08	1.4E+05	2.2E+02	2.8E+07	1.7E+03	6.5E+02	1.52	9124	64.15	9124	44.07	6.1E+04	9.5E+01	4.6E+06	2.8E+02	1.1E+02	5.43
11560	73.95	11560	54.84	1.3E+05	1.9E+02	2.4E+07	1.5E+03	5.5E+02	1.30	11453	73.20	11453	52.50	5.2E+04	8.1E+01	3.7E+06	2.3E+02	8.6E+01	4.41
Short Fire																			
216	0.00	216	0.00	2.7E+05	4.2E+02	5.7E+07	3.5E+03	1.3E+03	3.08	213	0.00	213	0.00	1.2E+05	1.8E+02	1.1E+07	6.5E+02	2.4E+02	12.44
1588	14.79	1588	15.42	2.3E+05	3.6E+02	4.8E+07	2.9E+03	1.1E+03	2.58	1559	14.64	1559	14.79	9.8E+04	1.5E+02	8.6E+06	5.3E+02	2.0E+02	10.14
3198	29.58	3198	29.49	1.9E+05	3.0E+02	3.9E+07	2.4E+03	9.0E+02	2.13	3149	29.28	3149	28.29	8.2E+04	1.3E+02	6.9E+06	4.2E+02	1.6E+02	8.15
3353	31.00	3353	30.84	1.9E+05	2.9E+02	3.9E+07	2.3E+03	8.9E+02	2.08	3283	30.51	3283	29.43	8.0E+04	1.2E+02	6.8E+06	4.1E+02	1.6E+02	7.99
Open Warehouse																			
1150	0.00	1150	0.00	2.7E+05	4.2E+02	5.7E+07	3.5E+03	1.3E+03	3.08	0	0.00	329	0.00	1.2E+05	1.8E+02	1.1E+07	6.5E+02	2.4E+02	12.44
18113	14.79	18113	9.83	2.4E+05	3.8E+02	5.0E+07	3.1E+03	1.2E+03	2.73	353	0.00	353	0.28	1.2E+05	1.8E+02	1.1E+07	6.4E+02	2.4E+02	12.40
27770	23.21	27770	15.42	2.3E+05	3.5E+02	4.7E+07	2.9E+03	1.1E+03	2.54	1590	14.64	1590	14.79	9.8E+04	1.5E+02	8.6E+06	5.3E+02	2.0E+02	10.14
										4110	29.28	4110	28.76	8.1E+04	1.3E+02	6.9E+06	4.2E+02	1.6E+02	8.10
										4230	29.84	4230	29.43	8.0E+04	1.2E+02	6.8E+06	4.2E+02	1.6E+02	8.01
										7225	43.92	7225	38.15	7.0E+04	1.1E+02	5.7E+06	3.4E+02	1.3E+02	6.65
										9260	56.23	9260	44.07	6.2E+04	9.6E+01	4.8E+06	2.9E+02	1.1E+02	5.69
										9644	58.56	9644	44.90	6.1E+04	9.4E+01	4.7E+06	2.9E+02	1.1E+02	5.53
										11564	73.20	11564	49.07	5.5E+04	8.6E+01	4.0E+06	2.4E+02	9.2E+01	4.71
										13193	87.84	13193	52.61	5.0E+04	7.8E+01	3.4E+06	2.1E+02	7.7E+01	3.96
										14638	102.48	14638	55.75	4.6E+04	7.1E+01	2.8E+06	1.7E+02	6.4E+01	3.28
										15801	117.12	15801	58.27	4.2E+04	6.5E+01	2.3E+06	1.4E+02	5.2E+01	2.66
										16071	121.11	16071	58.86	4.1E+04	6.4E+01	2.1E+06	1.3E+02	4.9E+01	2.50

										16791	131.76	16791	61.50	3.8E+04	5.9E+01	1.7E+06	1.0E+02	3.9E+01	2.02
										17627	146.40	17627	64.57	3.4E+04	5.3E+01	1.2E+06	7.3E+01	2.8E+01	1.42
										18202	161.04	18202	66.68	3.1E+04	4.9E+01	7.6E+05	4.7E+01	1.8E+01	0.90
										18848	175.68	18848	69.04	2.9E+04	4.4E+01	3.3E+05	2.0E+01	7.5E+00	0.38
										19288	190.32	19288	70.66	2.6E+04	4.1E+01	0.0E+00	0.0E+00	0.0E+00	0.00
										19673	204.96	19673	72.07	2.4E+04	3.7E+01	0.0E+00	0.0E+00	0.0E+00	0.00
										19973	219.60	19973	73.17	2.2E+04	3.5E+01	0.0E+00	0.0E+00	0.0E+00	0.00
										20063	224.93	20063	73.50	2.2E+04	3.4E+01	0.0E+00	0.0E+00	0.0E+00	0.00
										20220	234.24	20220	77.00	1.9E+04	3.0E+01	0.0E+00	0.0E+00	0.0E+00	0.00
										20400	248.88	20400	81.02	1.6E+04	2.4E+01	0.0E+00	0.0E+00	0.0E+00	0.00
										20580	263.52	20580	85.04	1.3E+04	2.0E+01	0.0E+00	0.0E+00	0.0E+00	0.00
										20695	278.16	20695	87.60	1.1E+04	1.7E+01	0.0E+00	0.0E+00	0.0E+00	0.00
										20719	282.34	20719	88.14	1.0E+04	1.6E+01	0.0E+00	0.0E+00	0.0E+00	0.00
										20779	292.80	20779	89.48	9.2E+03	1.4E+01	0.0E+00	0.0E+00	0.0E+00	0.00
										20839	307.44	20839	90.82	8.0E+03	1.2E+01	0.0E+00	0.0E+00	0.0E+00	0.00
										20869	322.08	20869	91.49	7.2E+03	1.1E+01	0.0E+00	0.0E+00	0.0E+00	0.00
2-Door Open Warehouse																			
333	0.00	333	0.00	2.7E+05	4.2E+02	5.7E+07	3.5E+03	1.3E+03	3.08	178	0.00	178	0.00	1.2E+05	1.8E+02	1.1E+07	6.5E+02	2.4E+02	12.44
18311	14.79	18311	9.74	2.4E+05	3.8E+02	5.1E+07	3.1E+03	1.2E+03	2.73	9608	14.64	9608	12.39	1.0E+05	1.6E+02	8.8E+06	5.4E+02	2.0E+02	10.41
28800	23.42	28800	15.42	2.3E+05	3.5E+02	4.7E+07	2.9E+03	1.1E+03	2.54	11438	17.30	11438	14.79	9.8E+04	1.5E+02	8.5E+06	5.2E+02	2.0E+02	10.04
										19688	29.28	19688	25.63	8.4E+04	1.3E+02	7.2E+06	4.4E+02	1.6E+02	8.42
										24908	43.92	24908	32.48	7.5E+04	1.2E+02	6.1E+06	3.7E+02	1.4E+02	7.20
Close Warehouse: NA																			